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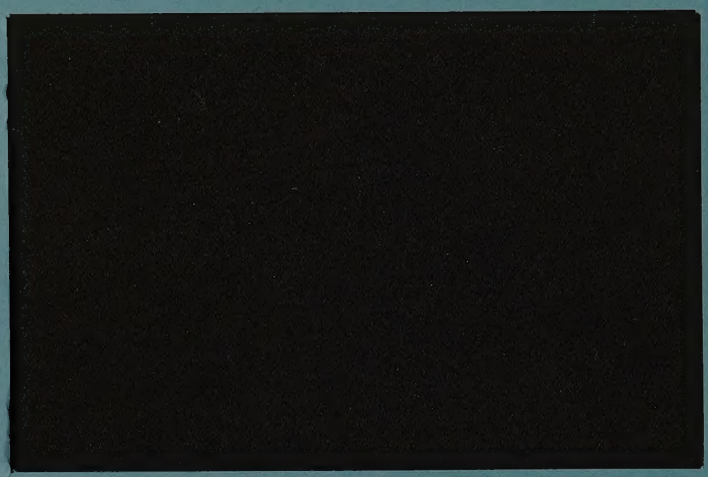
THE EFFECT OF ENVIRONMENTAL FACTORS ON THE RESPIRATORY HEALTH OF SCHOOLCHILDREN IN HAMILTON

CURRENT REPORT # 1

MARCH 1, 1979

URBAN AIR ENVIRONMENT GROUP

McMASTER UNIVERSITY



TO:

Health and Welfare Canada
Research Programs Directorate
Project 6606-1752-53

Ontario Ministry of the Environment
Air Resources Branch
Project 20

THE EFFECT OF ENVIRONMENTAL FACTORS ON THE RESPIRATORY HEALTH OF SCHOOLCHILDREN IN HAMILTON

CURRENT REPORT # 1

MARCH 1, 1979

Submitted by:

A. T. Kerigan and L. D. Pengelly
Department of Medicine

C. H. Goldsmith
Department of Clinical Epidemiology and Biostatistics

J. Shewchun
Department of Engineering Physics

McMaster University
Hamilton, Ontario
Canada

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6 Laser Reprint

PERSONNEL - SUPPORTED BY PROJECT FUNDS

Stephen Toplack	Project Manager & Supervisor of Air Monitoring
Bill Furlong	Air Monitoring Technician
Ruth Hershler	Data Manager
Liz Rebuck	Supervisor, Pulmonary Function Studies
Eva Corrigan	Pulmonary Function Technician
Danae Fraser	Assistant, Pulmonary Function Technician
Susan Radford	Pulmonary Function Technician
Gail Parker	Assistant, Pulmonary Function Technician
John Reid	Engineering Physicist
Nic Dalacu	Lab Technician
Ian Rabenda	Lab Technician
Mohammed El-Sherbiny	Doctoral Student
Fran Allen	Administrative Assistant

1. INTRODUCTION

The purpose of this report is to summarize, for the benefit of both of our sponsoring agencies (as well as for ourselves) the activities of this project. Formal approval of this project by Health and Welfare Canada was given on November 9, 1978, and by Ontario Ministry of the Environment on November 28, 1978. Having received some indication that the project would likely be approved, all but one of our personnel were hired and trained, the pulmonary function equipment was bought, delivered and calibrated, and pulmonary function studies started (after several hundred questionnaire interviews had already been completed) on November 27, 1978. Much of the initial thrust of energy on our part has been in getting the study of the schoolchildren under way, as three precious months of school time had been lost.

Two aspects of the work will be emphasized in this report: (1) a summary of the kind and extent of activities engaged in to date, and (2) a brief description of any significant departures from the original protocol, and the reasons for change.

2. QUESTIONNAIRE SURVEY

2.1 Choice of Sample: As detailed in the protocol, 30 schools have been randomly chosen to give a sample size of 3,200 in the age range 7-10. The location of these schools is shown on the accompanying map (p. 17/18) and their order of testing by their assigned number.

2.2 PROGRESS OF SURVEY: As of February 13th, schools 1-10 had been completed. The progress is as follows:

A.	Total assigned	1455
B.	Not eligible (age 11 before Dec. 31, 1978)	69
C.	Total eligible	1386
D.	Completed interviews	1334
E.	Completion rate (D/C%)	96.2%

F. Pulmonary Function consents obtained 1327

G. Consent rate (G/C%) 95.7%

The completion rate of 96.2% is in excess of the 85% expected, used to determine the number of children we would have to approach to obtain the required sample size. It is probable therefore that the last two to four schools in the schedule will not be utilized.

At the present rate of interviewing all the schools could be completed by June 15th. However, the rate of pulmonary function testing is, of necessity, slower and to ensure that all interviews are obtained no more than 8 weeks before testing, only 24 schools will be interviewed before the end of the school year.

With this level of completion rate for interviews and consent rate for pulmonary function testing, we consider that our survey techniques are adequate in this respect.

2.3 Interview Questionnaire: The final questionnaire was derived from that in the pilot study and is included as Appendix 1. Questions have been added concerning amount of cigarette smoking, familial respiratory symptoms and type of cooking fuel.

2.4 Quality Control: Procedures have been established to check accuracy of questionnaire data before inclusion in the data file. These are as follows.

2.4.1 Interviewer Verification: Each two weeks, eight interviewers are chosen randomly and the mother phoned by a person other than the original interviewer who asks two randomly chosen questions from the questionnaire. The results of these verifications are then compared with the original data using subprogram CROSSTABS (SPSS). The results from this are shown below:

Period	Interviews checked	# incorrect answers	Interviews never done
1	7	1 (7%)	0
2	7	3 (22%)	0
3	10	0 (0%)	0

2.4.2 Coding Verification: Questionnaires are randomly selected, re-coded and the two sets of coding cross checked. To date, the results from this are:

# variables checked (5% of all cases)	3,468
# variables in error	16
coding error rate	0.46%

2.4.3 Key Punch Verification: Keypunching is performed at the Computer Services Unit, MUMC. Every card is re-keypunched for verification.

2.4.4 Out-of-range Editing: Keypunching questionnaire data is then run through a program which pulls out all variables lying outside specified ranges, these errors being due to miscoding or keypunch error.

2.4.5 Interviewer Profile: To see if any systematic differences exist among the interviewers in terms of questionnaire replies, the rate of positive replies to questions 1, 4, 5, 12 and 28 are compared using subprogram CROSSTABS to see if there is any significant difference.

No significant differences have been found to date except for question 5 (Does the child have asthma?) For this question, the difference was due to a higher ratio of positive responses than expected from three of the fourteen interviewers. This difference was not due to local variation since this excess rate was a consistent finding for each interviewer in schools of different localities. To correct this, the mode of asking this question has been clarified with these interviewers. Further profiles will determine the effectiveness of this intervention.

3. PULMONARY FUNCTION TESTING

Summary

As set out in the proposal, two teams consisting of two people each are carrying out testing using the H.P. 47804A calculator based pulmonary function system. Eight schools have been completed in which over 1,000 children have been tested.

3.1. Progress of Pulmonary Function Testing: As is described in detail below, changes have been made in the testing protocol which involve the carrying out of a more comprehensive set of pulmonary function tests. The result of this has been that the number of tests completed per team per working day is 12.4 instead of the twenty which we had originally forecast. In spite of this, we have now completed pulmonary function testing in over 1,000 children. All of this data is subjected to quality control procedures and coded within two working days of being obtained, and so all of the data from the 1,000 children is now stored on magnetic tape, as well as in the form of punched cards.

Preliminary analysis of these data has been carried out and indicates to us (as much as we have confidence in data from the literature) that all of the measurements for which we have comparison agree in general with the results of others. It is to be noted that this study will increase by an order of magnitude the data base for predictions of pulmonary function for some variables in this age range. Further details of the results of the pulmonary function testing will be found in section 3.5, Quality Control.

3.2. System Hardware and Logistics

3.2.1. Equipment: Two pulmonary calculator systems were obtained from Hewlett-Packard (Canada) Limited early in the summer of 1978. To facilitate moving of the equipment, and to provide for its protection

during this process, both systems were installed in metal desks modified by the McMaster University Medical Centre Bioengineering Department; both systems had been installed by the end of November 1978. These modifications included fitting each desk with industrial casters and protective electrical equipment. Timers were added in order to overcome delays in testing due to low overnight room temperatures in some schools. Before moving into a school, the pulmonary function and 'moving' teams both make a preliminary visit to each school to brief the principal about our plans. At the same time, an inspection is made to determine if there are access or electrical problems connected with the room to be used for the testing. In the larger schools, the gymnasium is checked for these same points, as an assembly of the classes to be tested is held within a day of moving into each school. A short explanation of our purpose in coming into the school is presented to the students to reduce their concern and that of their teachers.

3.2.2. Transportation: During the first three months of testing, from mid November 1978, to mid February 1979, transportation of the two pulmonary calculator systems and their accessories was provided by the McMaster University Operations and Maintenance Department, by means of tarpaulin-equipped stake trucks each fitted with a power tail gate. During this period, it was determined that this system, while mostly adequate, was greatly affected by vehicle and worker availability, and by weather; it also did not provide sufficient flexibility for our needs. It was also found that, to lift the systems up and down stairs, four to six men were required, depending upon the direction, and the number of steps. While many of the newer public elementary schools have been built on one level, most of the older ones have several; unfortunately, none of these have been equipped with elevators. A decision was made during this three-month period to obtain a leased van for the exclusive use of this project. Expected advantages included improved flexibility, permanent placement of equipment in the van, and greater protection of the equipment from the weather.

Originally, it was envisioned that this vehicle would provide most of the heavy transportation for all three aspects of this project. At present, it is being used by the epidemiological and particulate sections of the project; co-ordination with the needs of the SO_2 section is beginning. Of course, new developments may result in changes in the implementation of this plan.

3.3. Calibration: Cross check calibrations were carried out with both systems on both pneumotachs with a Collins Spirometer. Also the two calibrating syringes were cross-checked with both systems on both pneumotachs. The results showed a difference of less than 1% between the two systems and between the two syringes.

To calibrate the nitrogen meter, a number of 200 ml syringes containing varying concentrations of nitrogen from 0% to 78% and remainder pure oxygen, were passed through the system and the nitrogen reading recorded and plotted. Both systems showed the usual non-linear response of nitrogen analysers, but the responses were consistent. In addition a two litre syringe was used to simulate a lung of two litres' TLC. Both the single breath and multiple breath washout tests were repeated several times to look at the reproducibility of lung volumes. The results showed clearly that the greater consistency was observed from the multiple breath method. On this basis we decided to add the multiple breath test as a separate measurement. In addition, routine calibration and documentation of both pneumotachs are done twice a day with a syringe, and the coefficient of variation for both systems is less than 1%.

3.4. Criteria Procedures for Pulmonary Function Testing: Before starting on the first school whose data would be used in the final study, we chose 20 students in a school to help us familiarize ourselves with the new equipment and aid in the training of the new technicians. Each student was tested twice and as a result of this experience, we were able to test the reproducibility of our results and identify difficulties with the techniques.

Some changes in the order of tests and the tests performed occurred based on this experience. As a result, we developed a formal protocol and set of criteria, (see Appendix 2). We found that the closing volume test was the most difficult for the children to perform, so it is now done as the last test when the children are more relaxed and familiar with the equipment. The technicians try up to four closing volume manoeuvres from which two are chosen if the VC's are within 10% of the best previous VC and 5% within each other. We have found this to be more satisfactory. The order of testing is now: multiple washout, then three forced expired manoeuvres, spirometry, (a slow vital capacity breath following quiet breathing) and then up to four closing volumes.

For the multiple breath washout to be acceptable there must be no leaks around the mouthpiece and the child must be relaxed. This will be observed by a consistent fall in nitrogen concentration. For the forced expired volumes to be acceptable there must be two where the FVC's are within 5% of each other. For the spirometry to be acceptable, the FRC must be stable and the VC within 10% of the previous best VC. If it is not, then the spirometry is repeated. If the VC's on the closing volume are larger than 10% of the previous FVC then another FVC is performed. With these changes in testing and criteria each team is able to test at least 10 children per day. The results are returned each day to McMaster and the following working day, the results undergo quality control and are coded, ready for keypunching.

3.5. Quality Control

3.5.1. Coding: All lung function data are coded by two coders. Coders alternate schools each day. One out of 20 records coded is randomly selected for verification by the second coder. The recoded data is accumulated until 10 records have been recoded by each coder and then the coded and recoded records are compared and a summary of the coding errors tabulated. At this stage of our study

we have done 20 verifications per coder and each demonstrates an error rate of less than 1%.

All the coded data is keypunched and then verified by a second keypuncher reducing the possibility of keypunch errors to less than .001%.

Two IBM cards are used for each child to receive coded information. The first card contains all the information on the child including age, birthdate, sex, weight, height and ambient room conditions including temperature, humidity and Barometric Pressure. The coded variables can be seen by reference to the coding form (see Appendix 3).

The second card has the basic information as on the first with some additions (see Appendix 4). This card is mainly used for the comparison between the two possible ways of measuring lung volumes with the H.P. system, either from the closing volume manoeuvre or from the combination of multiple washout and spirometry.

3.5.2. Criteria and Protocol for Coding: Criteria and a protocol (see Appendix 5) were developed for the coders under the following guidelines: Some information was purely transcribed, e.g. height, weight; some information required a preliminary stage of interpretation on the basis of the figures alone. A further set of information required interpretation based on the graphic records as well as the numerical ones following our developed criteria. These criteria were: in the multiple washout, the measurement of FRC was acceptable only if the nitrogen concentration fell gradually to 1%. For the forced expired manoeuvres, two FVC had to be within 5% of each other. In the closing volume manoeuvres a number of criteria were adopted. Firstly, the VC had to be within 10% of the largest VC. Secondly, the spirometric trace had to show that FRC was stable and that there was an observable ERV/IC manoeuvre. Thirdly, if two closing volumes had VC within 5% of each other and were within 10% of largest VC then the results were averaged.

Our experience found that simple transcription of data was carried out speedily and with few errors. Data that needed some interpretation such as spirometric data, took more time, but was easy to carry out once our criteria were developed.

The most time - consuming and technically demanding aspect of this work was the last category, mainly reflecting the difficulty of analysis of the closing volume test. Most of the coders' time was spent in scrutinizing the results from this test.

3.5.3. Preliminary Analysis of Stored Data: Before permanently storing the lung function data for analysis, each record is run through a range checking program which pulls out variables that are either out of range or miscoded. The range for each lung measurement is obtained by taking Mean $\pm$ 2S.D.,where these values were obtained from the results of the pilot study.

As the teams of pulmonary technicians complete a pair of schools, measurements of FVC (Forced Vital Capacity), MEF75 (Max.-Expired Flow at 75%), MET (Mid-Expired Time), TLC (Total Lung Capacity), N2DIFF (Nitrogen Difference) are compared for each team by parallel line regression analysis i.e. regression lines for each of these measurements by height are obtained for each team and by means of analysis of variance it is considered whether these lines are parallel and/or coincident. At this stage we have been able to examine the first two schools completed by each team and were able to demonstrate no differences by this analysis between teams. A summary of the results for FVC only for the first four schools is shown in Table 3-1.

Scattergrams, as a school is completed, are obtained for FVC and MET by height and age. See Fig. 3-1.

The degree of success of the test procedures are evaluated, team by team, as four schools are completed, by calculating percentages of missing values for the measurements of FVC, VC (Vital Capacity), RV (Residual Volume), CV (Closing Volume) and N2DIFF. See TABLE 3-2.

TABLE 3-1

FVC by Height

	Null hypothesis		F-value (degrees freed)	F.95 critical value	Results
	Ho1	Team B	1.97 (5, 188)	2.21	model OK
0.18 =SLOPE	Hoa	01 & 04	228.87 (1, 193)	3.84	slope~0
0.69 =INTERCEPT	Ho1	Team A	.86 (7, 309)	2.06	model OK
	Ho1a	02 & 03	357.55	3.84	slope~0
0.18 =SLOPE					zero
	Ho2		1.28 (12, 497)	1.75	model OK
0.75 =INTERCEPT	Ho2a	parallel	.00 (1, 497)	3.84	lines par.
	Ho2b		585.43		slope~0
	Ho3		1.18 (13, 497)	1.67<F<1.75	model OK
	Ho3a	coincident	8.09 (1, 510)	3.84	lines coinc.
	Ho3b		587.05		slope~0

FILE REPSTUDY (CREATION DATE = 1/26/79) RESPIRATORY FUNCTION STATUS OF SCHOOL CHILDREN
SCATTERGRAM OF (DOWN) FVC FORCED VITAL CAPACITY (ACROSS) HT HEIGHT IN CM

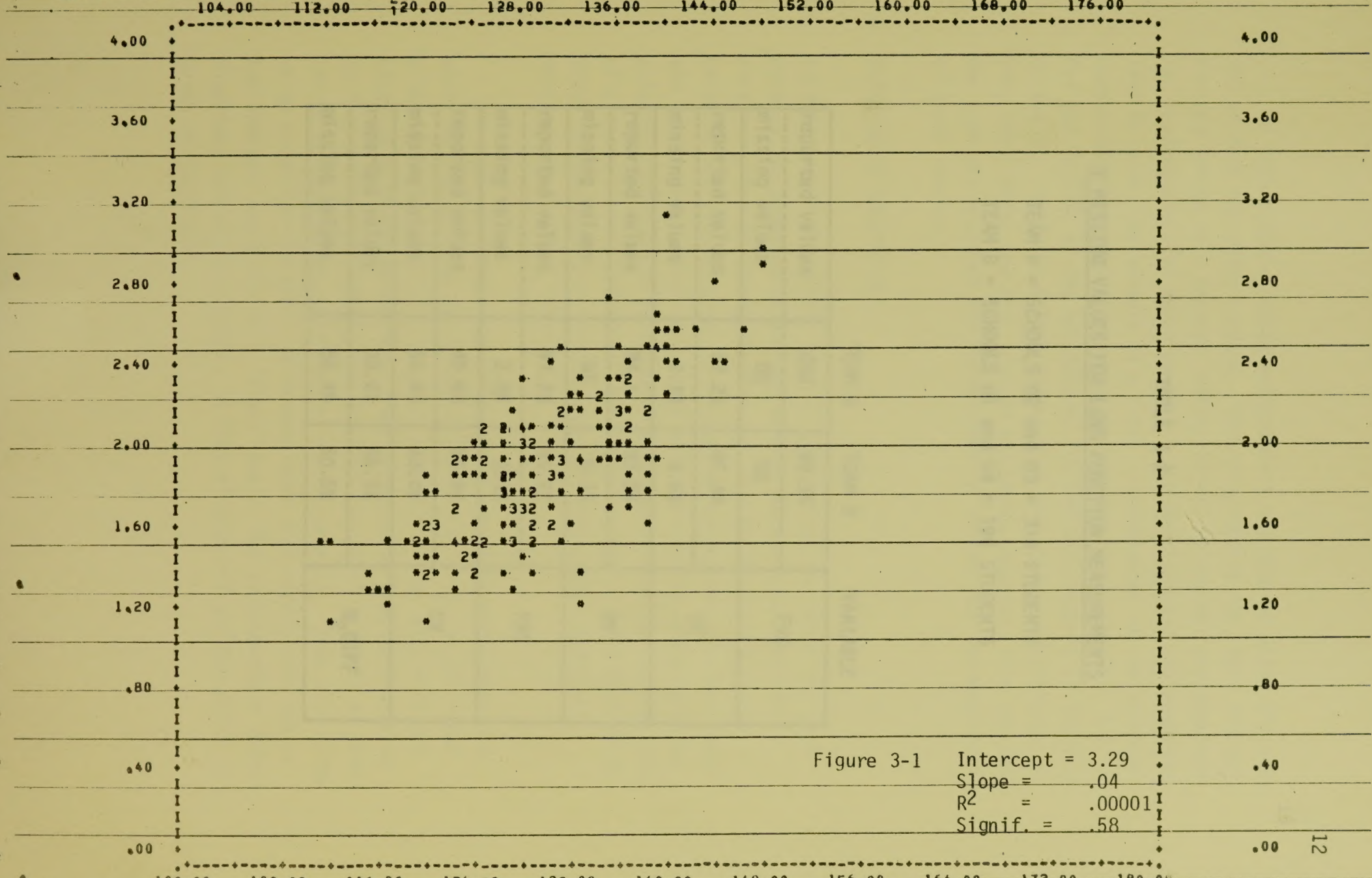


Figure 3-1 Intercept = 3.29
Slope = .04
R^2 = .00001
Signif. = .58

TABLE 3-2

% MISSING VALUES FOR LUNG FUNCTION MEASUREMENTS

TEAM A = SCHOOLS 02 and 03 = 318 STUDENTS

TEAM B = SCHOOLS 01 and 04 = 195 STUDENTS

	TEAM A	TEAM B	VARIABLE
reported values	100%	99.5%	FVC
missing values	0%	5%	
reported values	97.2%	95.4%	VC
missing values	2.8%	4.6%	
reported values	94 %	93.9%	RV
missing values	6%	6.1%	
reported values	97.2%	96.9%	FRC
missing values	2.8%	3.1%	
reported values	45.6%	56.6%	CV
missing values	54.4%	43.4%	
reported values	33.6%	49.5%	N_2DIFF
missing values	66.4%	50.5%	

At each school, repeat measurements are made on eight children, two of each age being studied. The measurements FVC, FEV1 (Forced Expired Volume in 1 second), MEF50, CV/VC, RV and MET are examined for repeatability by ANOVA on SPSS. The measurements are examined team by team, two schools at a time. Scattergrams of the original measurements by repeat measurements are obtained. See Fig. 3-2 for the results of the scattergram for FVC measurements of schools 03 and 06. We found a high correlation for repeat measurements of FVC, FEV1, MEF50 and MET. For RV and CV/VC, however, this was not the case and measures are being taken to improve the reproducibility of these results.

4. PARTICULATE MONITORING

4.1. Outdoor Sampling Network: In our application for funds for this project, we proposed to add ten outdoor particulate sampling stations (five in the upper city and five in the lower) to our existing Hamilton particulate network of three stations (one upper and two lower). These were to be operated synchronously with the existing nine Ontario Ministry of Environment stations in the lower city and with two stations of our rural network. There were to be seven Particulate Size Distribution and eight Total Suspended Particulate stations overall.

To date, we have established three new upper city locations, with two others to be established soon. Similarly, in the lower city, we have established four new sampling sites, also with one other to be established soon. Additionally, we hope to obtain up to four additional high-volume samplers (hi-vols) in April of 1979 (to be borrowed from the Ministry of Environment). This will allow us to establish two more, permanent lower city sites, with one or two samplers available on a "float" basis, for supplementary investigations and other purposes. A list of both old and new sites is given in Table 4-1.

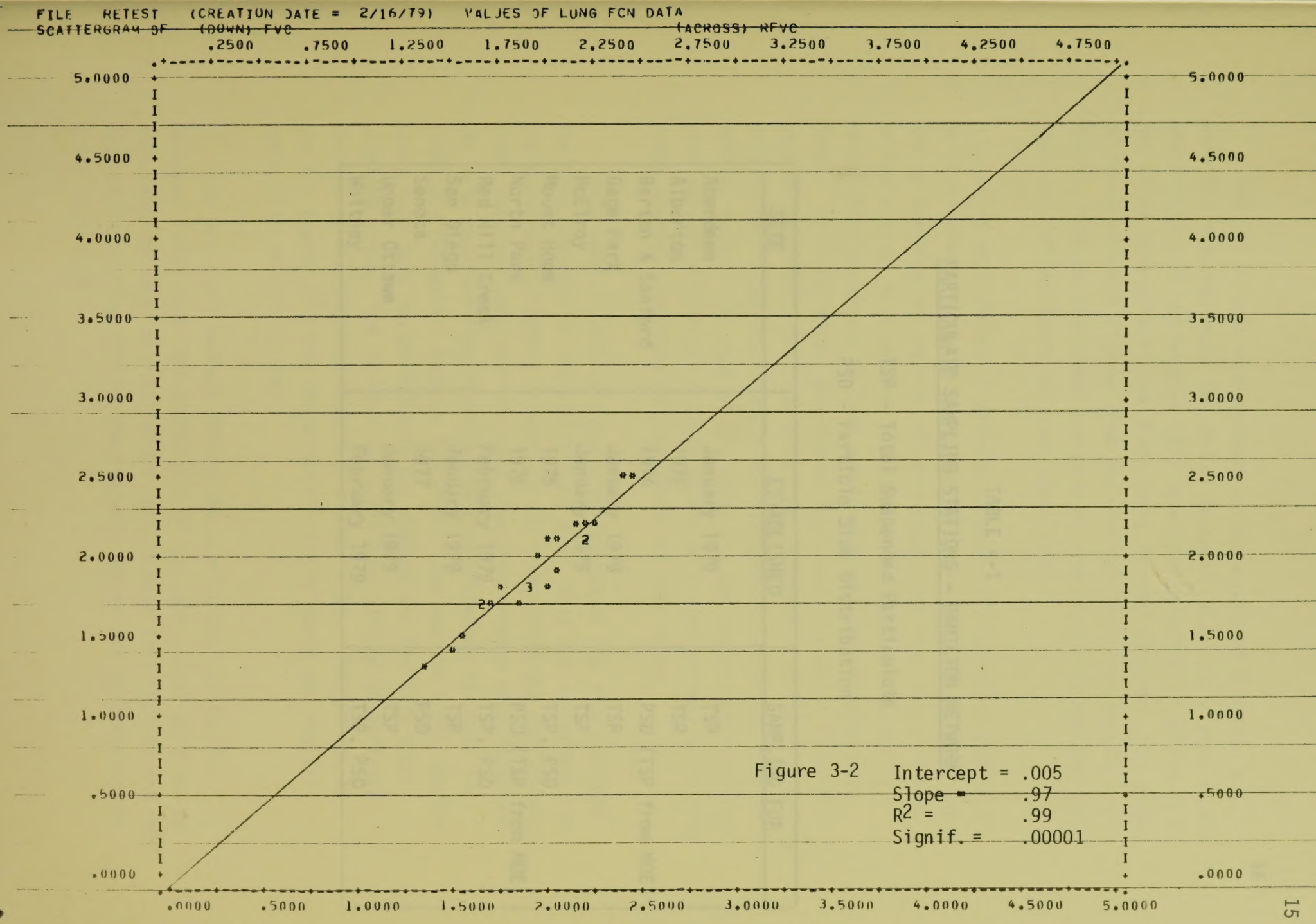

FILE RETEST (CREATION DATE = 2/16/79) VALJES OF LUNG FCN DATA
SCATTERGRAM OF (DOWN) FVC (ACROSS) RFVC
.2500 .7500 1.2500 1.7500 2.2500 2.7500 3.2500 3.7500 4.2500 4.7500
5.0000
4.5000
4.0000
3.5000
3.0000
2.5000
2.0000
1.5000
1.0000
.5000
.0000
.0000 .5000 1.0000 1.5000 2.0000 2.5000 3.0000 3.5000 4.0000 4.5000 5.0000
Intercept = .005
Slope = .97
R2 = .99
Signif. = .00001

Figure 3-2

TABLE 4-1

PARTICULATE SAMPLING STATIONS - HAMILTON NETWORK

TSP - Total Suspended Particulate

PSD - Particle Size Distribution

SITE	ESTABLISHED	SAMPLING FOR
Aberdeen	January 1979	TSP
Alberton	1975	TSP
Barton & Sanford	1976	PSD (TSP from MOE)
Gage Park	January 1979	TSP
McElroy	January 1979	TSP
Mount Hope	1975	TSP, PSD
North Park	1976	PSD (TSP from MOE)
Red Hill Creek	February 1979	TSP, PSD
San Diego	January 1979	TSP
Seneca	1977	PSD
Upper Ottawa	January 1979	TSP
Whitney	February 1979	TSP, PSD

Ten new hi-vols were ordered in the middle of October, but were not received until the end of December 1978. As a result, all new stations in the network will have been established during 1979. New sites were established using these ten new machines, two reconditioned samplers (spares from the Hamilton-Nanticoke Particulates Study), and one additional new machine ordered during January 1979 when our further needs had been identified.

Sites were chosen to provide as much information as possible on particulate levels in the vicinity of the schools selected for the epidemiological section of this study (see Fig. 4-1). Where suitable sites were readily available, samplers were placed in residential backyards so that sampling height approximated nose level. In other areas, one-storey roof-tops were used; later on, we plan to compare readings from these machines with those of nearby ground-level samplers, using a non-assigned or "floating" sampler for the latter. At some of the sites, it has proven necessary to have outdoor electrical outlets installed at our expense to provide power sources complying with building and fire codes.

From July 1, 1978,originally envisioned as the start-up date for this project, to the end of that year, data was collected from the previously existing network of two Total Suspended Particulates (TSP) Samplers, and four Particle Size Distribution (PSD) samplers. The data obtained from these samplers is presented in Table 4-2 (TSP) and Tables 4-3 through 4-6 (PSD). Two new TSP - PSD sampler pairs have been established at the Whitney and Red Hill Creek sampling sites. One further TSP - PSD pair will be established shortly at the Highview site in the upper city. This brings to six the number of sites where correlation of these two measurements will be carried out.

Two new staff members joined the particulate section in October, 1978; from then to the end of the year, major portions of time were occupied by preparatory work in both this section and the epidemiological section of the project, and by the epidemiological study logistics.

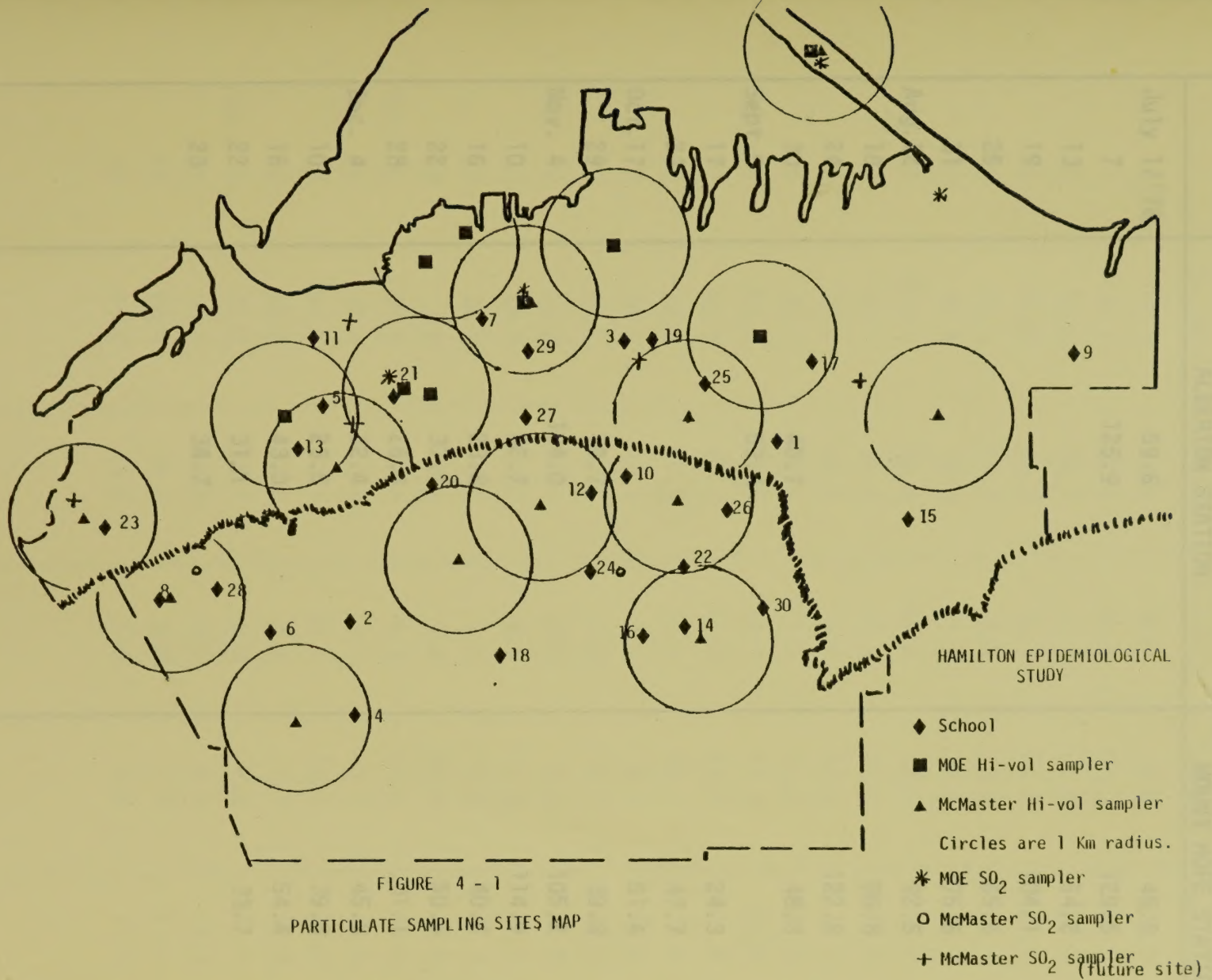


FIGURE 4 - 1

PARTICULATE SAMPLING SITES MAP

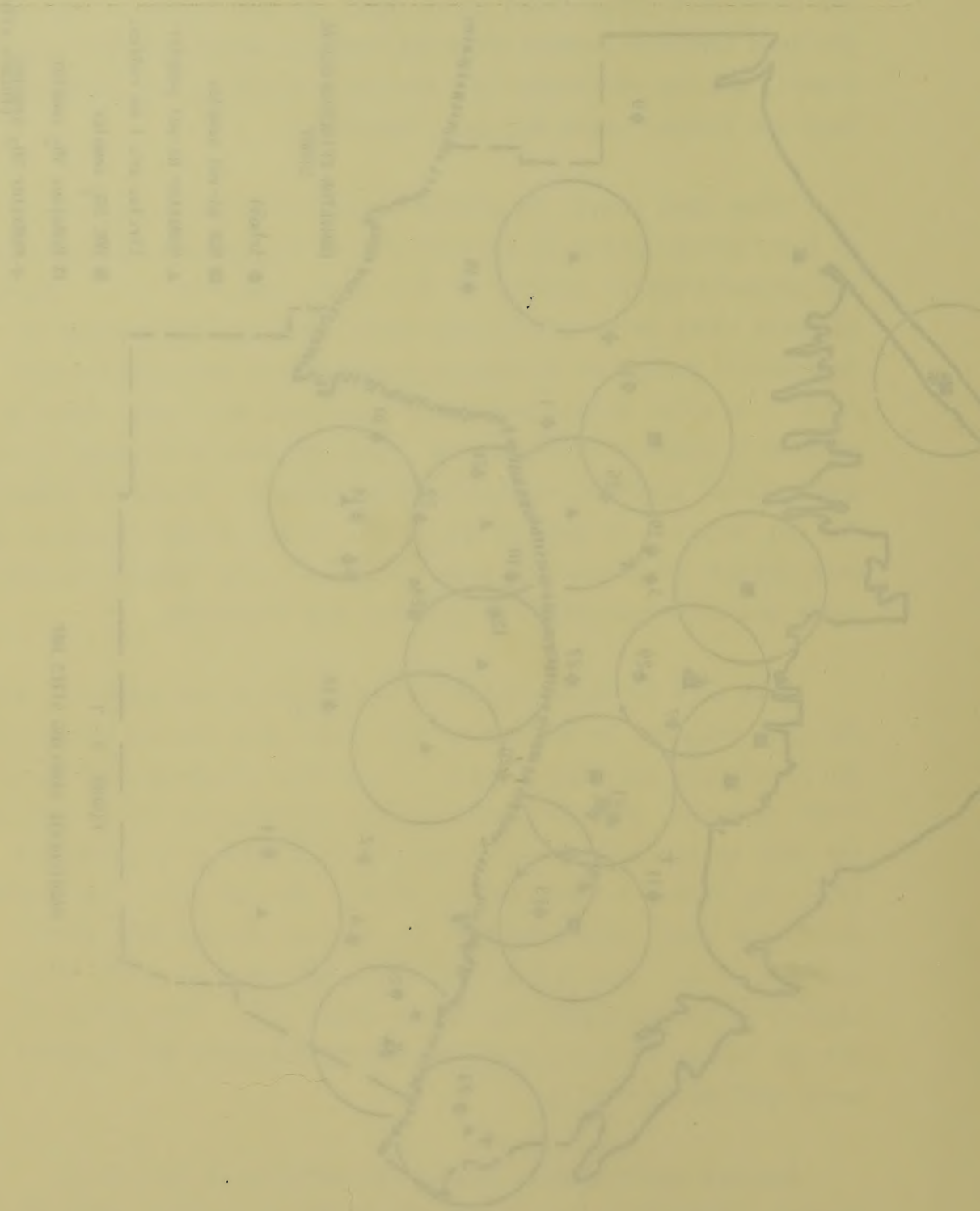


TABLE 4-2

DATA OF TOTAL SUSPENDED PARTICULATE LOADINGS

DATE	CONCENTRATIONS IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$)	
	ALBERTON STATION	MOUNT HOPE STATION
July 1/'78	59.6	48.5
7	125.9	129.5
13		54.2
19		104.1
25		65.5
31		75.6
Aug.12		92.5
18		96.8
24		122.8
30	40.7	48.3
Sept.5	57.4	
17		24.3
23		47.7
Oct.17		51.4
29	19.7	39.8
Nov. 4	104.0	105.2
10	82.7	114.9
16	23.8	40.6
22	37.1	50.5
28	26.4	31.1
Dec. 4	32.4	45.8
10	23.5	39.8
16	43.0	54.4
22	31.1	33.7
28	34.7	

TABLE 4-3

PARTICLE SIZE DISTRIBUTION DATA

STATION - MOUNT HOPE

DATE	CONCENTRATIONS IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$)					
	> 7.0	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	TOTAL LOAD
July 1/'78	18.3	19.8	10.0	9.5	18.3	75.9
7	39.7	25.5	15.9	22.3	57.0	160.4
13	16.9	10.7	7.1	6.8	20.3	61.8
19	24.9	24.7	10.4	14.2	49.6	123.8
25	33.7	11.7	14.0	13.2	26.7	99.3
31	36.9	19.3	11.9	11.9	38.3	118.3
Aug. 12	223.5	96.6	82.2	77.1	96.8	576.2
18	46.1	26.6	17.3	16.2	41.6	147.8
24	41.9	26.6	14.5	27.2	114.7	224.9
30	33.4	9.1	1.9	15.1	30.4	89.9
Sept. 5	54.9	25.2	14.1	11.4	29.4	135.0
11	45.8	25.6	12.8	24.2	59.2	167.6
17	16.2	15.1	12.0	10.1	18.5	71.9
23	16.1	12.1	4.5	5.8	13.6	52.1
29	24.7	13.5	7.9	9.4	47.0	102.5
Oct. 5	19.5	15.3	4.8	8.3	17.9	65.8
17	38.3	15.7	9.9	11.5	77.5	152.9
23	15.7	8.5	3.2	4.2	12.5	44.1
29	7.9	8.6	9.8	23.8	15.5	65.6
Nov. 10	50.9	19.6	9.1	11.0	46.4	137.0
16	17.4	6.2	3.5	3.7	12.8	43.6
22	21.6	14.4	10.7	14.3	20.2	81.2
28	15.2	11.6	8.4	7.7	12.9	55.8
Dec. 4	21.8	10.7	5.6	8.5	22.9	69.5
10	8.7	8.8	4.2	6.1	9.4	37.2
16	28.2	12.1	6.8	7.7	23.1	77.9
22	21.6	13.2	2.8	9.0	12.0	58.6

TABLE 4-4

PARTICLE SIZE DISTRIBUTION DATA

STATION - SENECA

DATE	CONCENTRATIONS IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$)					
	> 7.0	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	TOTAL LOAD
July 1/'78	29.9	20.8	14.0	10.8	19.9	95.4
7	19.6	22.8	17.2	20.1	56.7	137.4
13	29.8	21.0	14.7	13.0	29.6	108.1
19	41.7	26.1	15.9	12.6	40.0	136.3
25	30.4	25.9	13.5	13.5	27.5	110.8
31	48.7	20.2	13.5	14.2	45.8	142.4
Aug. 12	102.6	84.6	73.1	74.6	83.9	418.8
30	27.9	16.3	13.8	8.7	8.3	75.0
Sept. 5	35.4	22.4	13.9	10.2	22.8	104.7
11	31.3	21.5	16.3	29.1	48.4	146.6
17	19.3	15.0	9.0	9.1	12.7	65.1
29	24.4	16.9	10.1	7.8	15.2	74.4
Oct. 5	15.9	12.9	8.3	5.8	11.9	54.8
17	21.9	12.7	7.9	7.4	13.0	62.9
29	18.4	12.1	10.4	9.4	16.1	66.4
Nov. 4	26.6	16.8	12.5	18.9	47.0	121.8
10	46.2	22.9	11.5	12.4	44.6	137.4
16	21.8	10.7	5.0	6.1	23.7	67.3
22	20.5	17.9	6.6	8.0	26.0	79.0
28	12.1	10.1	7.4	8.1	11.3	49.0
Dec. 4	14.7	11.6	4.8	6.5	10.7	48.3
10	9.4	7.4	2.7	5.8	8.2	33.5
16	22.4	12.4	9.4	9.2	22.6	76.0
22	14.7	9.1	4.5	7.8	15.5	51.6
28	12.1	7.2	5.9	6.3	18.9	50.4

TABLE 4-5

PARTICLE SIZE DISTRIBUTION DATA

STATION - BARTON and SANFORD

DATE	CONCENTRATIONS IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$)					
	> 7.0	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	TOTAL LOAD
July 1/'78	33.3	14.1	10.5	8.5	14.9	81.2
7	67.9	35.1	150.1	26.3	71.1	350.5
13	47.6	29.4	21.4	16.9	41.7	157.0
19	59.7	40.3	19.6	13.4	71.4	204.4
25	45.4	37.8	25.0	23.5	57.3	189.0
31	76.9	28.0	18.3	16.5	58.3	198.0
Aug. 12	132.6	87.7	74.0	76.4	98.7	469.4
30	48.1	18.4	7.0	11.1	66.4	151.0
Sept. 5	62.9	28.5	19.3	15.3	34.9	160.9
11	51.7	20.9	11.9	16.9	97.9	199.3
17	32.8	20.7	15.4	18.8	19.7	107.4
23	33.7	19.8	14.3	8.8	25.2	101.8
29	66.4	27.9	15.5	13.9	34.3	158.0
Oct. 5	36.2	22.8	16.4	8.9	20.9	105.2
17	39.7	23.2	12.9	17.8	30.7	124.3
23	24.2	10.8	6.3	4.9	14.6	60.8
29	26.3	13.4	10.5	10.6	24.3	85.1
Nov. 10	75.0	24.2	14.0	16.1	56.0	185.3
16	43.6	25.5	9.8	15.5	44.2	138.6
22	46.4	20.6	11.9	12.3	58.2	149.4
28	23.5	12.4	10.6	12.9	38.4	97.8
Dec. 4	34.9	18.8	12.6	12.5	20.3	99.1
10	31.9	16.7	4.4	10.5	18.9	82.4
16	52.0	23.2	13.2	14.7	29.1	132.2
22	39.8	19.5	12.1	11.9	21.2	104.5
28	29.5	12.1	8.6	8.8	19.8	78.8

TABLE 4-6

PARTICLE SIZE DISTRIBUTION DATA

STATION - NORTH PARK

DATE	CONCENTRATIONS IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$)					
	> 7.0	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	TOTAL LOAD
Aug. 18/'78	34.3	22.1	6.4	12.1	28.4	103.3
24	72.0	33.7	22.5	29.7	113.6	271.5
30	40.1	30.9	9.1	9.4	32.8	112.3
Sept. 5	88.8	38.5	23.6	24.6	115.0	290.5
11	79.3	39.9	28.3	34.4	98.9	280.8
17	46.3	18.0	12.7	14.4	79.5	170.9
23	23.1	15.2	10.7	8.7	22.3	80.0
29	45.7	19.9	14.2	10.9	28.4	119.1
Oct. 5	62.7	30.4	14.9	14.8	41.3	164.1
17	48.8	20.7	14.1	11.6	26.1	121.3
23	14.5	59.6	9.7	7.0	16.9	107.7
29	N/A					
Nov. 4	111.6	34.3	31.9	46.9	110.1	334.8
10	55.4	10.4	4.4	5.4	28.4	104.0
16	36.5	12.3	5.9	1.0	14.2	69.9
22	48.3	12.9	7.6	8.6	18.9	96.3
28	55.4	21.7	17.0	17.2	48.1	159.4
Dec. 4	90.5	40.2	30.2	27.2	105.8	293.9
10	91.8	44.4	29.4	25.6	67.4	258.6
16	120.3	35.2	21.5	23.1	55.9	256.0
22	94.7	39.1	24.0	22.1	51.1	231.0
28	66.4	27.5	14.7	15.8	37.1	161.5

4.2. INDOOR SAMPLING

During the summer of 1978, two students were involved in researching various aspects of indoor sampling, in connection with an Experience '78 grant provided by the Ontario Ministry of Environment. This study, which is serving as a basis for further work within the project, consisted of the following:

1. a thorough literature search for recent work on indoor/outdoor air quality measurement;

2. locating or designing an instrument suitable for indoor sampling; and

3. carrying out preliminary indoor/outdoor sampling for calibration purposes.

An indoor sampler based on a modified cannister "shop-vac" vacuum cleaner, fitted with a 4" diameter filter head, was tested. This sampler was found to be considerably quieter than the hi-vol used for comparison. Other advantages included a motor that did not over heat at the voltages utilized, and the price, which was considerably lower than others on the market.

Paired indoor (low-volume) and outdoor (high-volume) particulate sampling was carried out at two sites: a storage building on the McMaster University campus, and a residence located in the west end of the upper city. It was determined that the results obtained could not be taken as more than crude approximations of actual indoor air quality, due to variable flow rates. Further work is to be carried out to develop a reliable flow controller for this portion of the study. We are also investigating the use of sound insulating materials to reduce levels of noise produced by the lo-vol sampler based on a vacuum cleaner.

4.3. Co-ordination of Data: Data obtained from both indoor and outdoor particulate samplers will be coded in forms compatible with the requirements of the epidemiological study programs.

5. SO_2 MONITORING

SO_2 Monitoring: In our pilot study, we demonstrated that considerable SO_2 gradients can exist in Hamilton. There was a factor of two difference in SO_2 levels (24 hour average) between the two school districts examined, one in a "low pollution" area (Seneca School) and the other in a "high pollution" area (Prince of Wales School). Our study calls for a survey of 3000 children. Hamilton has an approximate student population of 9000 children in the 7-10 range and the schools draw their pupils from the immediate surrounding area. We estimate that approximately 20 school districts will need to be monitored over the course of the study in order to achieve a desired stable population of 3000 children. These districts are being selected on a uniform basis across the city with respect to the population distribution of children across the city. Each of these 20 districts will then be characterized with regard to its SO_2 level. This will be implemented during the present year.

At present, The Provincial Ministry of the Environment (MOE) has four monitoring stations in Hamilton with two in operation only since 1976. Data is not available from all four on a continuous basis. In particular, there is no coverage of the mountain area which is expected to have a low pollutant dose and where a significant fraction ($\sim$40%) of the school children are located. This and the fact that the monitors employed by the MOE (Beckman 906A SO_2 analyzers) were not originally intended for low level measurements with any high degree of accuracy and suffer from calibration and stability problems, demand a better monitoring strategy for SO_2. Fortunately, it is possible to deploy Beckman instruments to monitor the low levels of SO_2 frequently encountered by careful and frequent calibration of the instruments against the Laser Absorption Spectrometer (LAS) we have developed at McMaster.

This LAS is in itself a highly accurate and versatile point monitor and we believe it is a successor to the type of chemical instruments being deployed for monitoring in many parts of the world. Our technological capability in this is well established as is reflected in three scientific papers (peer reviewed) which have appeared recently in the scientific literature. One of the papers is reprinted in Appendix 6 to give some idea of our extensive capability in this area. As a result, our initial strategy is to use the LAS to keep in calibration 7 Beckmans (we already have two in our possession, Mr. L. Shenfeld is to provide an additional two; three have been ordered and delivery is imminent). With these Beckmans we will monitor at the 20 locations for 4 months out of the year (once in each of the four seasons). This will give us a reasonable indication of the pollution level of each school district and allow us to determine whether the school districts selected are adequate. The LAS will also be used to monitor other gases such as NO_x and O_3 to determine whether their levels are of such a magnitude that they could affect the respiratory function of the children and thus influence the study which has initially been defined only in terms of SO_2.

At the present time, as indicated earlier, the Ministry of the Environment has monitoring stations at Barton-Sanford, North Park, Hamilton City Hall and Woodward Avenue Municipal Laboratories. The locations of these stations, some of which operate on an intermittent basis only are indicated in Fig. 4-1.

As far as possible, we shall integrate the data obtained from these stations with that obtained from our own monitoring using calibrated systems. One glaring lack in the present monitoring network is the total lack of monitoring stations on the "Mountain". Accordingly, we have concentrated initially on deploying the available Beckman instruments in the area above the escarpment. Thus, two monitors have been installed in this area, one at Macassa Lodge, on Upper Sherman, and the other at Chedoke Hospital on Sanatorium Road.

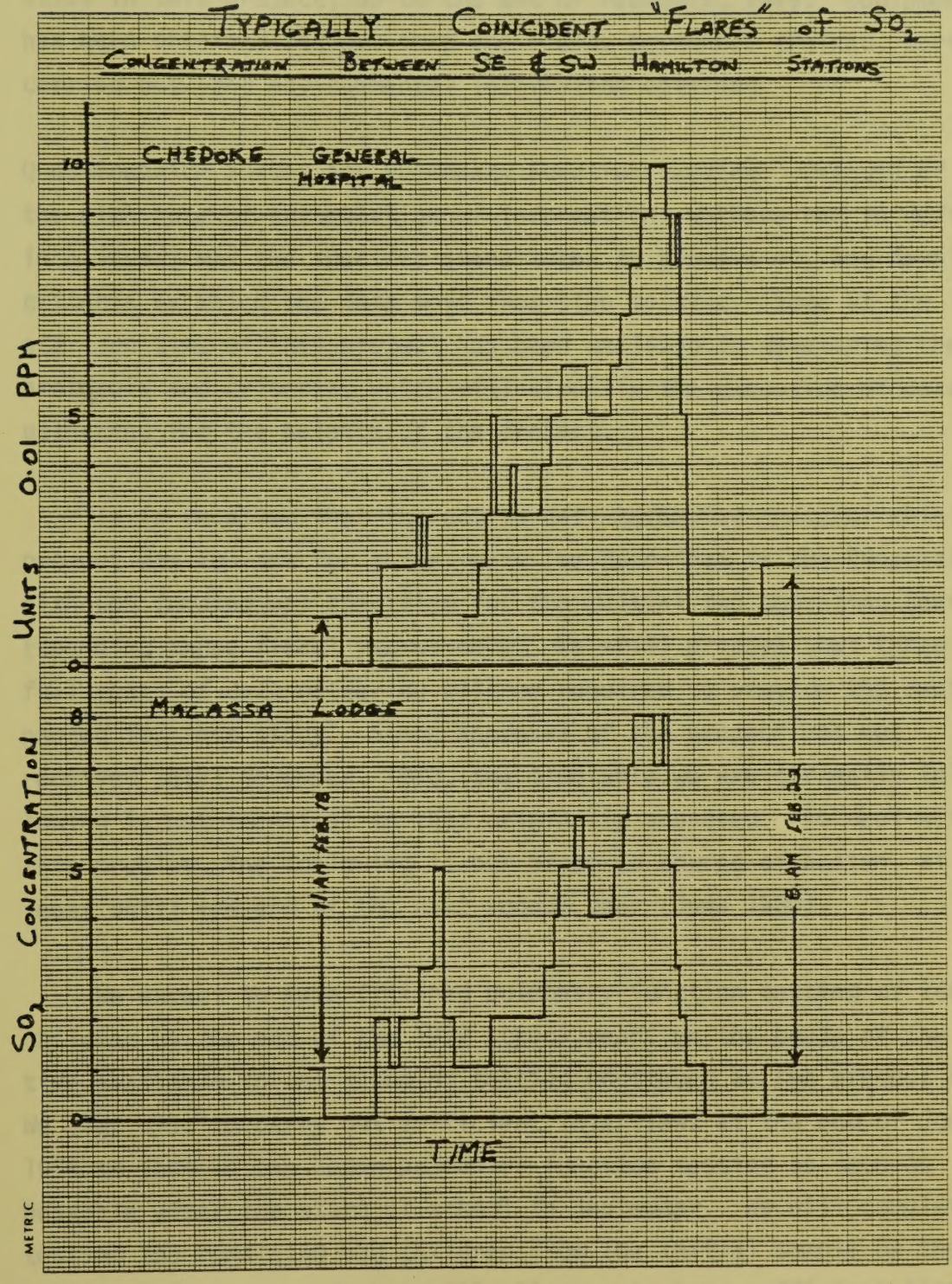
The sites of these two stations, which are operational and accumulating data, are indicated in Fig. 4-1. Over the period for which monitoring has been under way, it is found that the measured SO_2 concentrations are very similar for the two stations, located at the eastern and western ends of the mountain.

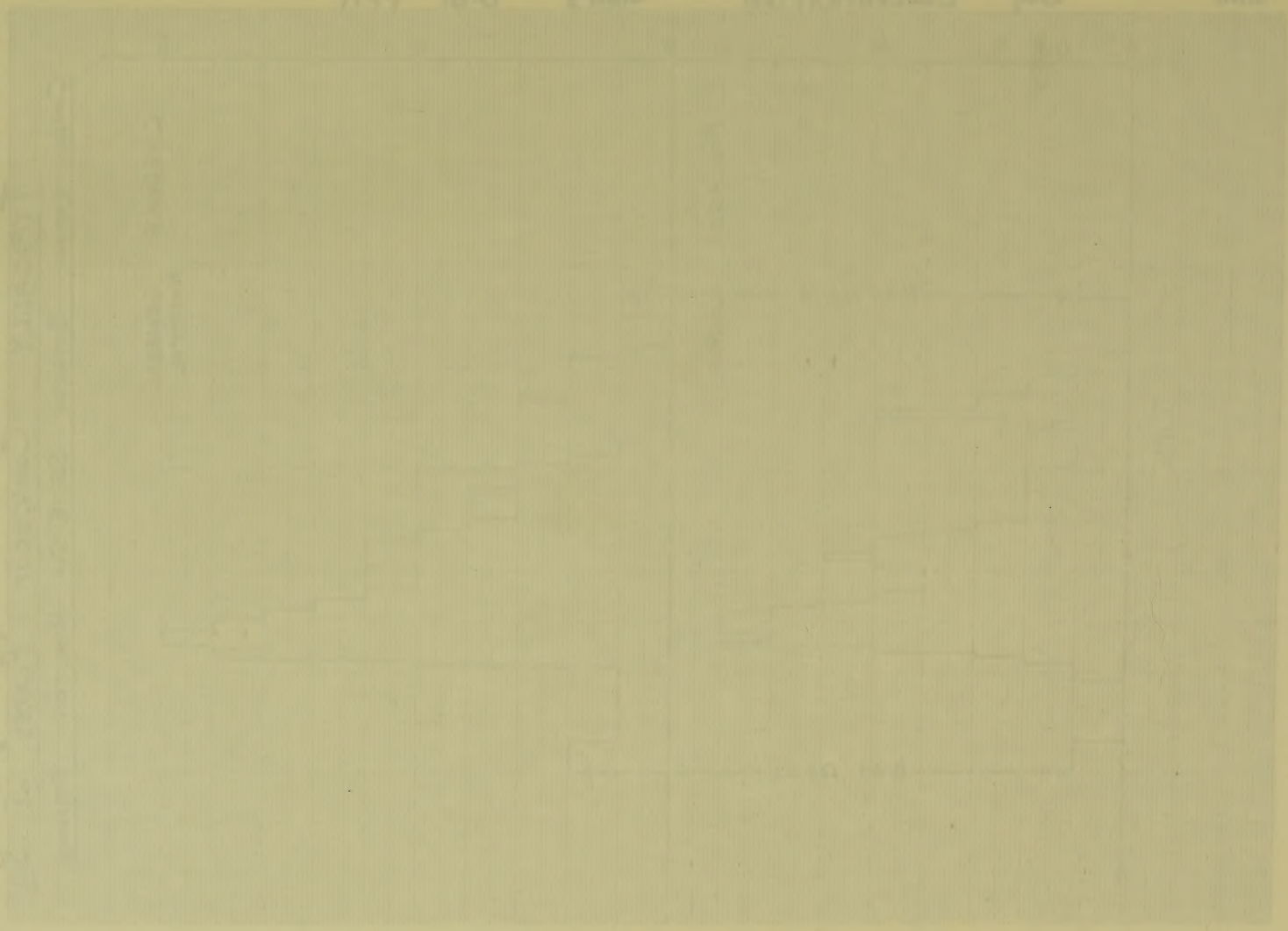
In our first month of operation our two stations in south Hamilton have shown very similar SO_2 level variations as is demonstrated by our graph of one particular acute SO_2 level "flare" shown in Fig. 5-1. Such simultaneous episodes appear to be the rule rather than the exception between these two stations. Unfortunately, we have not yet received the MOE data for their downtown stations for the same period. However, data from the preliminary "77" study shows the occurance of such wide variations in dose levels is also a characteristic of downtown stations and stations adjacent to the industrial centre, and is a characteristic of the SO_2 level pattern in Hamilton.

A third Beckman which is in our possession is presently in our lab for calibration with the Laser Absorption Spectrometer. We are rotating the Beckman analyzers to the lab so that each one is systematically calibrated. It is this procedure which will improve the recovery of low level dose information. Later we will transport an improved, more portable, LAS prototype between stations to give us an indication of other pollutant levels as well as to maintain calibration of the Beckmans.

As the additional Beckman systems are received, they will be deployed in stations established at the premises of selected schools throughout Hamilton. The Hamilton School Board has given permission for the implementation of this scheme. The sites selected for initial deployment of the additional Beckman monitors are Scott Park, Ryerson, Hess, Sir Winston Churchill and Binkley schools, the locations of which are indicated on Fig. 4-1. These will be rotated to new locations after three months.

Figure 5-1


TYPICALLY COINCIDENT "FLARES" of SO_2
CONCENTRATION BETWEEN SE & SW HAMILTON STATIONS
CHEDOKE GENERAL HOSPITAL
MACASSA LODGE
SO_2 CONCENTRATION UNITS 0.01 PPM
10
5
0
8
5
0
11 AM FEB 18
8 AM FEB 19
TIME
METRIC



6. CONCLUSIONS

We have described briefly in this report a summary of our activities in this project, up to the end of February, 1979. Equipment has been obtained and put into the field, personnel trained, surveys carried out, and environmental information obtained.

6.1. Questionnaire Survey and Pulmonary Function Testing: Because of the high rate of accumulation of information, we have had to define in a formal way the specific steps taken to process it, and develop criteria by which the data move from step to step. Some of the start-up time of this project has been utilized in developing these protocols and criteria, which will simplify the execution of data gathering for the balance of the project.

It is recalled that the active data-gathering phase of this project was to last for three years (as described in the Proposal) although funding was specified for the initial two operating years (spanning three fiscal years) only. We still propose that three full years of data gathering will be required to provide the depth needed for this study. Since approval of the project was not received until November, 1978, the timetable we are currently following is not identical to that originally proposed. To deal with this problem, the following is our proposed course of action, at least until the end of the next school year (June 1980).

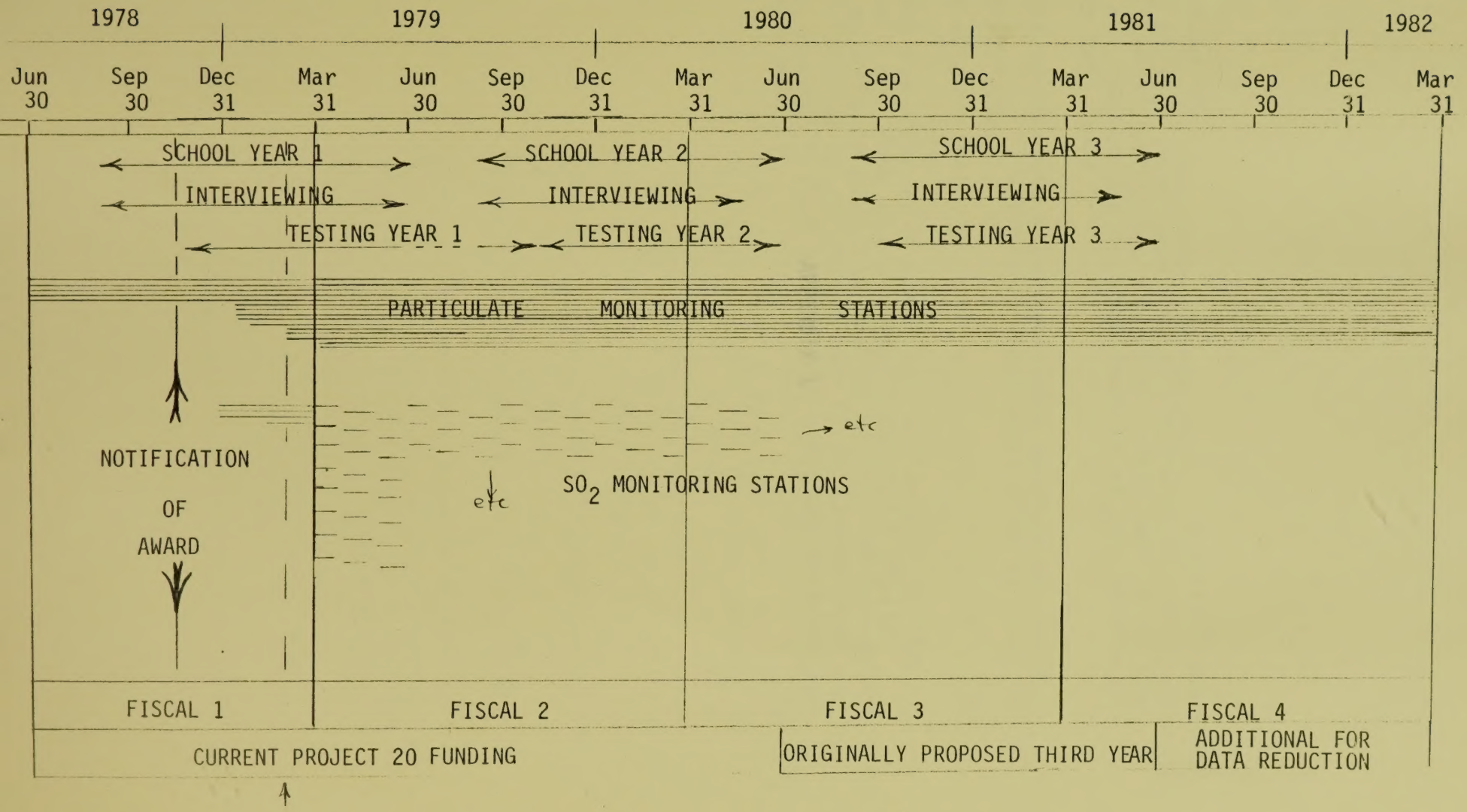
We expect to have finished pulmonary function testing of 2600 children by the end of the 1979 school year, on the basis of the time available to us, assuming testing continues at the present rate. We plan also to carry out sufficient interviews at the end of June 1979 so that we can begin pulmonary function testing as soon as possible after the start of school in September. We will complete testing the remaining 600 children from the initial sample by the middle of October, and that will allow us to have sufficient time to finish the complete second round of interviewing and testing by June 1980.

Thus by June 1980 we will have interviewed and tested our 3200 child sample twice, except that we will expect to have lost a small number of children due to the fact that they will have moved out of the Hamilton area. For a graphical indication of our planning strategy see Fig. 6-1.

6.2. Environmental Monitoring: In the first year we will have obtained a sample of environmental information from our first network of stations which will likely lead us to shift one or two locations slightly to account for local anomalies which will only become apparent after having run the network for a few months. By the fall of 1979 we will have defined the final network design, and the system design will then remain fixed for the rest of the study. At the same time we should have our indoor monitor system working well, and locations established and operational. Thus during the second study year we should have a complete and comprehensive set of environmental information to complement the epidemiological data, and the continuation of the study into its third and final year of data collection will provide us with all of the data the study will require.

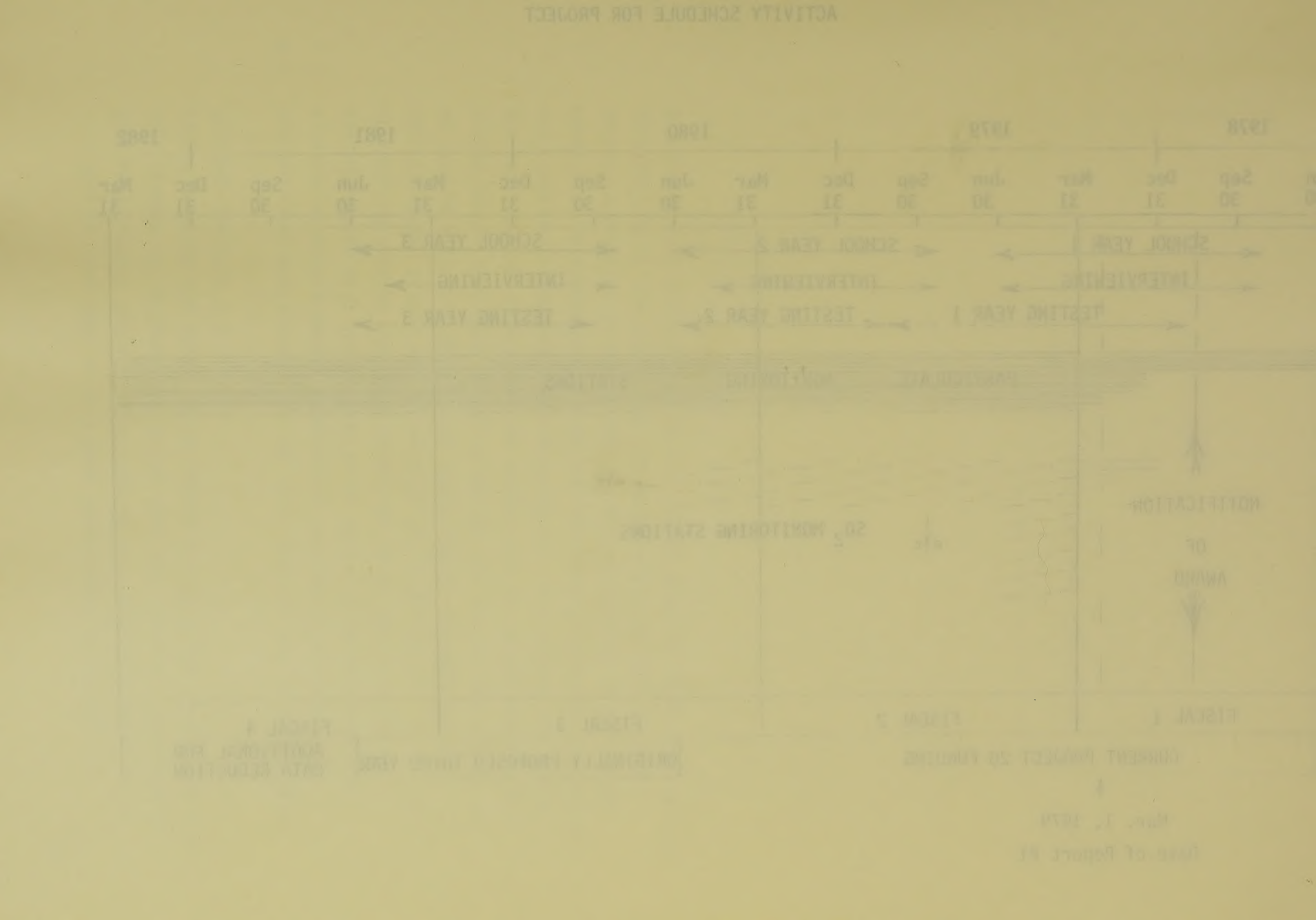
TABLE 6.1

ACTIVITY SCHEDULE FOR PROJECT



Mar. 1, 1979

Date of Report #1



APPENDIX 1

Hello, my name is _____. (I telephoned you earlier to arrange this time for an interview/You have probably received a letter informing you of my visit and about the survey we are conducting on some aspects of the health of children in Hamilton).

I would like to ask you some questions about your child _____'s health, which will take up only 15 or
(child's first name)
20 minutes of your time.

May I remind you that your name will not appear on the questionnaire and your answers will therefore remain anonymous as well as strictly confidential. Of course your participation is voluntary and if we should come to a question you don't want to answer, just let me know and we will skip over it.

Interviewer Note:

These boxes are the ONLY ones to be filled in by the interviewer.

The remaining boxes are to be filled in at the office by the coders.

I.D. # School [ ][ ] (1 2) Respondent [ ][ ][ ] (3 5)

Card # [1] (6)

Date of Interview [ ][ ] [ ][ ] [ ][ ] (7 12)
Day Mo. Yr.

Interviewer # [ ][ ] (13 14)

The first few questions are about your child's health. Could you please answer each one with a "yes" or "no".

1. Does _____ usually cough in the morning, not counting
child's name
just clearing the throat or a single cough?

( )1. Yes → 1a. Does (he/she) cough like this most mornings for as much as three months in a row each year? [ ] 15

( )1. Yes *( )7. Ref.*
( )2. No *( )8. D.K.*
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

[ ] 16

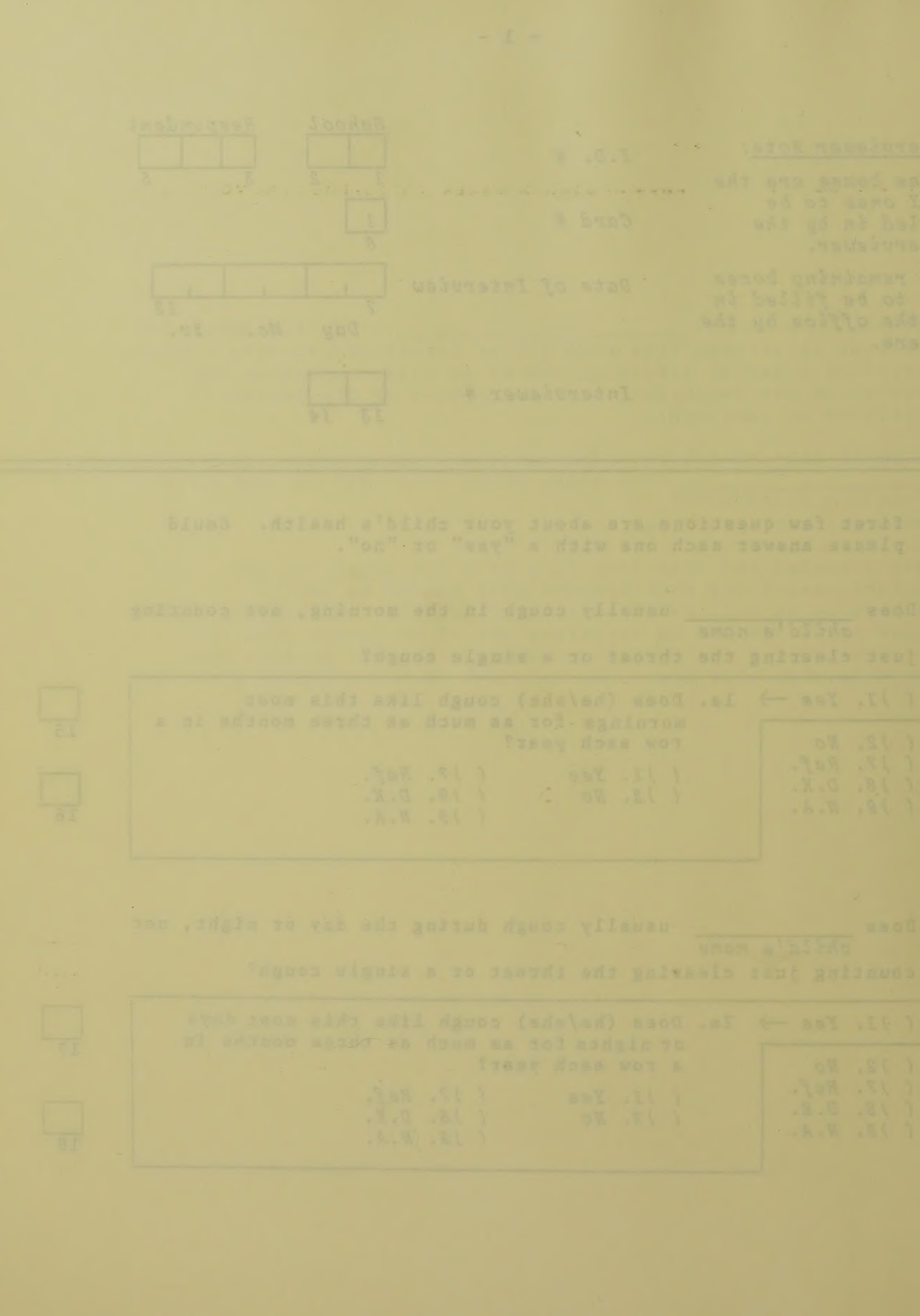
2. Does _____ usually cough during the day or night, not
child's name
counting just clearing the throat or a single cough?

( )1. Yes → 2a. Does (he/she) cough like this most days or nights for as much as three months in a row each year? [ ] 17

( )1. Yes *( )7. Ref.*
( )2. No *( )8. D.K.*
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

[ ] 18



3. Does (his/her) chest EVER sound wheezy or whistling?

( )1. Yes → 3a. Does (he/she) get this most days or nights -- by most I mean five or more days or nights a week throughout the year?

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

19 ☐

20 ☐

4. Has _____ suffered from asthmatic attacks in the last twelve months?
child's name

For clarification: Has a doctor ever told you it was asthmatic?

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

21 ☐

5. When _____ has a cold, does it usually go to (his/her) chest?
child's name

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

22 ☐

6. Has (he/she) had any cold in the last month?

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

23 ☐

7. During the last twelve months has _____ had a period of cough and phlegm lasting for 3 weeks or more?
child's name

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

24 ☐

8. During the last twelve months, has _____ had any chest illness such as bronchitis or pneumonia which has kept (him/her) at home for one week or more?
child's name

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

25 ☐

The next few questions are about your home and family.

9. Is your (home/apartment) heated by a forced air system?

( )1. *Yes*
( )2. *No*
( )7. *Ref.*
( )8. *D.K. - Probe!*
( )9. *N.A.*

Interviewer: If R. says don't know, look and check or ask about air ducts - yes, forced air air vents - yes, forced air electric baseboard - no hot water radiator - no

26

10. Do you cook by electricity, gas, or something else?

( )1. *Electricity*
( )2. *Gas*
( )3. *Electricity plus microwave*
( )4. *Gas plus microwave*
( )5. *Something else - specify* _____
( )7. *Ref.*
( )8. *D.K.*
( )9. *N.A.*

27

Interviewer: If you already know Q.11, you may ad lib -- but check.

11. Is _____ 's mother living with (him/her) at the moment?
child's name

( )1. *Yes*

28

( )2. *No* → 11a. Does _____ have a female guardian or some other person who lives with (him/her) and acts as (his/her) mother?
child's name

( )1. *Yes*
( )2. *No*
( )7. *Ref.*
( )8. *D.K.*
( )9. *N.A.*

29

IF THERE IS NO FEMALE GUARDIAN OR MOTHER GO TO Q.14.

12. (Do you/Does she) usually cough first thing in the morning, not counting just clearing the throat or a single cough?

( )1. *Yes* → 12a. (Do you/Does she) cough like this most mornings for as much as three months in a row each year?

30

( )1. *Yes*
( )2. *No*
( )7. *Ref.*
( )8. *D.K.*
( )9. *N.A.*

31

( )2. *No*
( )7. *Ref.*
( )8. *D.K.*
( )9. *N.A.*

3. (Do you/Does she) usually cough during the day or night, not counting just clearing the throat or a single cough?

( )1. Yes → 13a. (Do you/Does she) cough like this most days or nights for as much as three months in a row each year? ☐ 32

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

☐ 33

Interviewer: If you already know Q.14, you may ad lib -- but check.

4. Is _____ *child's name* 's father living with (him/her) at the moment?

( )1. Yes ☐ 34

( )2. No → 14a. Does _____ *child's name* have a male guardian or some other person who lives with (him/her) and acts as (his/her) father?

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

( )7. Ref.
( )8. D.K.
( )9. N.A.

☐ 35

IF THERE IS NO MALE GUARDIAN OR FATHER GO TO Q.17

15. (Do you/Does he) usually cough first thing in the morning, not counting just clearing the throat or a single cough?

( )1. Yes → 15a. (Do you/Does he) cough like this most mornings for as much as three months in a row each year? ☐ 36

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

☐ 37

16. (Do you/Does he) usually cough during the day or night, not counting just clearing the throat or a single cough?

( )1. Yes → 16a. (Do you/Does he) cough like this most days or nights for as much as three months in a row each year? ☐ 38

( )1. Yes ( )7. Ref.
( )2. No ( )8. D.K.
( )9. N.A.

( )2. No
( )7. Ref.
( )8. D.K.
( )9. N.A.

☐ 39

. Altogether, how many rooms are there in this (home/ apartment) that are used for living, not counting the bathroom?

_____ *(number)* 40 41

. How many bedrooms do you have in your home -- by bedrooms I mean rooms set aside for sleeping - it doesn't matter whether they are currently used for that or not?

_____ *(number)* 42

. How many people altogether live in this household, including yourself?

_____ *(number)* 43

. In total, how many children under 15 years of age live in this household, including _____ ?
child's name

_____ *(number)* 44

ONLY ONE CHILD GO TO Q.23

. Not counting _____ *child's name*, (does the other child) (how many of these children) usually cough during the day or night, apart from just clearing the throat or a single cough?

_____ *(number)* 45

. Not counting _____ *child's name*, (has the other child) (how many under 15) during the last 12 months have had any chest illness such as bronchitis or pneumonia which have kept them at home for a week or more?

_____ *(number)* 46

. How many other people sleep in the same room as _____ ?
child's name

_____ *(number)* 47

. Could you give me the ages of anyone living in this (home/apartment) who smokes either cigarettes, cigars or a pipe?

If there are no smokers check ⟶ ( ) and go to Q.25.

For each one listed ask: 24a. How much does _____ smoke on an average day?
Probe: If you had to guess what would you say?

1.	_____ *age*	_____ *# cigarettes*	_____ *# cigars*	_____ *# pipefuls*	48 49 50 51
2.	_____ *age*	_____ *# cigarettes*	_____ *# cigars*	_____ *# pipefuls*	52 53 54 55
3.	_____ *age*	_____ *# cigarettes*	_____ *# cigars*	_____ *# pipefuls*	56 57 58 59
4.	_____ *age*	_____ *# cigarettes*	_____ *# cigars*	_____ *# pipefuls*	60 61 62 63
5.	_____ *age*	_____ *# cigarettes*	_____ *# cigars*	_____ *# pipefuls*	64 65 66 67

5. Now I would like to ask a few questions about the places where _____ *child's name* has lived.

How long has _____ *child's name* lived at (his/her) present address?

68 70

_____ *(years)* _____ *(months)*

OTE: IF 3 YEARS OR MORE — GO TO Q.26

5a. *Hand Map to R.* What number on this map would best describe the most recent place that _____ lived?
child's name

If in doubt of which # to use, record CITY

AND COUNTRY _____ _____ *Map #* [ ] 71

b. How long did he live there? _____ *Years* - *If 3 or more years total, go to Q.26* [ ][ ] 72 73

2nd most recent _____ *Map #* _____ *Years* - *If 3 or more years total, go to Q.26.* [ ] 74 [ ][ ] 75 76

3rd most recent _____ *Map #* _____ *Years* [ ] 77 [ ][ ] 78 79

ASK EVERYONE

I.D.# [ ][ ] 1 2 [ ][ ][ ] 3 4 5

6. There are just a few questions left.

If there is no (father/male guardian), go to Q.27.

Card # [2] 6

What type of work does _____'s (father/guardian)
child's name *(anyone in father role)*
usually do?

Probe for DETAILS: [ ][ ][ ][ ] 7 10

_____

_____

_____

a. What industry is that?

_____

If (father/guardian) is disabled, deceased, retired or unemployed, ask:

26b. What was (his/your) usual occupation?

Probe for DETAILS: [ ][ ][ ][ ] 11 14

_____

26c. What industry was that?

_____

If there is no (mother/female guardian), go to Q.28.

27. What type of work does _____'s (mother/guardian) usually do?
child's name

Probe for DETAILS:

15 | | | | 18

_____

_____

_____

_____

IF "HOUSEWIFE" PROBE FOR PREVIOUS EMPLOYMENT AND check here → ( )Housewife

27a. What industry is that?

_____

If (mother/guardian) is disabled, deceased, retired or unemployed, ask:

27b. What was (her/your) usual occupation?

Probe for DETAILS:

19 | | | | 22

_____

_____

27c. What industry was that?

_____

AND RESPONDENT INCOME CARD

28. Now would you look at this card. Could you tell me which letter on the card corresponds to your present total family income before taxes for 1978.

Probe: If you had to guess, what would you say?

23 | | 24

( )01. A. Under $5,000
( )02. B. $ 5,000 - $ 7,499
( )03. C. $ 7,500 - $ 9,999
( )04. D. $10,000 - $12,499
( )05. E. $12,500 - $14,999
( )06. F. $15,000 - $17,499
( )07. G. $17,500 - $19,999
( )08. H. $20,000 - $22,499
( )09. I. $22,500 - $24,999
( )10. J. $25,000 - $27,499
( )11. K. $27,500 - $29,999
( )12. L. $30,000 or more
( )77. Refused
( )88. Don't know
( )99. Not applicable

Thank you for your co-operation.

NTERVIEWER'S PAGE

heck type of dwelling Respondent lives in

) 0. single detached
) 1. duplex, or semi-detached
) 2. row house
) 3. unit in a converted house
) 4. unit in small apt. building (no more than 6 units)
) 5. unit in larger apartment building, no more than three floors.
) 6. unit in high-rise building
) 7. mobile home
) 8. other (specify) _____

_____

□ 25

ho was interviewed?

) 1. Mother or female guardian
) 2. Father or male guardian ⟶ Why was mother not available
) 3. Other - _____ specify

( ) 1. Not living
( ) 2. Ill
( ) 3. Temporary absence
( ) 4. Other

□ 26

□ 27

ength of interview _____(minutes)

□□□ 28 30

lease record anything of importance that might not come hrough in the interview itself.

_____

_____

_____

APPENDIX 2

PROTOCOL AND CRITERIA TO BE USED BY THE PULMONARY FUNCTION TESTERS IN THE SCHOOLS

February 27, 1979

PROTOCOL

1. Instruct child before each test as to what is required.

2. Make sure child is relaxed; that lips are sealed; nose clip is on.

3. NWm (x1) - seated: Make sure that nitrogen is falling; if not, test will be invalid. Allow child to breathe quietly until 1% N_2 is detected. Machine will automatically stop at about 0.8%.

4. FVC (x3) - This test is performed while standing. The child breathes in room air to TLC, inserts FVC pneumotach with clean mouthpieces into mouth and gives a forced rapid expiration to RV followed by a forced inspiration back to TLC. The expiration must last for at least 1 second for machine to record results.

5. Spirometry (x1 conditional on criteria). This is done seated, with FVC pneumotach. Allow child to breathe quietly for a few breaths then into TLC out to RV; continue breathing quietly for a few breaths.

6. NWs (x2 up to 4 attempts made) - This is done seated. A few tidal breaths are made until the machine signals ready and then the child expires to RV. Override is pressed and then O_2 automatically switches on. At RV, the child then inspires at a flow of 0.3 - 0.5 L/sec. to TLC and then expires at that flow rate to RV.

7. General - There must be 10 quiet breaths before activating machine and four breaths before manoeuvre for NWs and Spirometry. There must be three quiet breaths after manoeuvre for NWs and Spirometry. This is to help in achieving a stable FRC.

8. Short report for all children. Add long report if results have been asked for or if you feel child has respiratory problem. (see criteria).

9. Colds to be reported as slight, upper respiratory heavy, and lower respiratory heavy.

CRITERIA

1. General - care must be taken to ensure good seal at mouthpiece - that the child is relaxed and makes maximum effort.

2. NWm - Nitrogen must fall consistently till 1% N2 is detected.

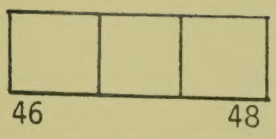
3. If two best VC's are not within 5% of each other, another FVC is performed.

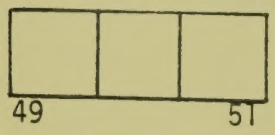
4. Spirometry - Stability of FRC established as less than 200 ml difference between pre and post VC levels. (By eye, the scale is too small for measurement). VC compared with best FVC; if less than 10% spirometry repeated, if more than 10% FVC repeated. If ERV is less than 20% and more than 50% of VC, test must be repeated. If there is more than 10% difference in the ERV/VC ratio for the two tests, a third test must be done.

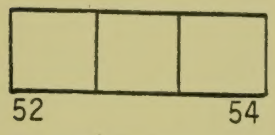
5. NWs - i) VC must be within 10% of largest previous VC.
   ii) Spirometry must look O.K. FRC must be stable with an obvious ERV, IC manoeuvre present (scale too small to measure).
   iii) If VC greater than 10% of largest previous VCs repeat FVC. Two acceptable manoeuvres are to obtained and up to four attempts must be made to obtain these.

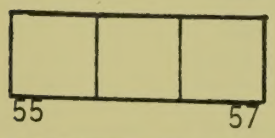
6. Long reports - These are made if asked for by parents and if both the FVC/FEV_1 ratio is less than 75% and the MET is greater than 0.75s.

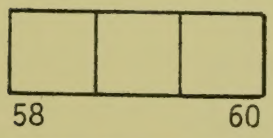
APPENDIX 3

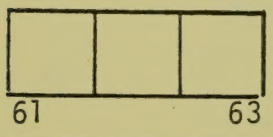
FEV1 

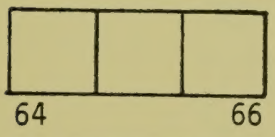
FEF 25-75 

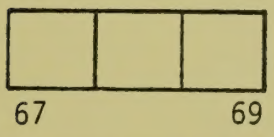
PF 

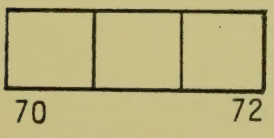
MEF 50 

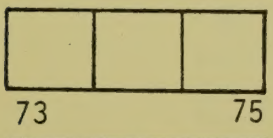
MEF 75 

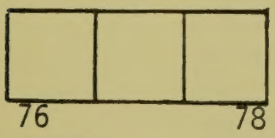
MET 

VC 

RV 

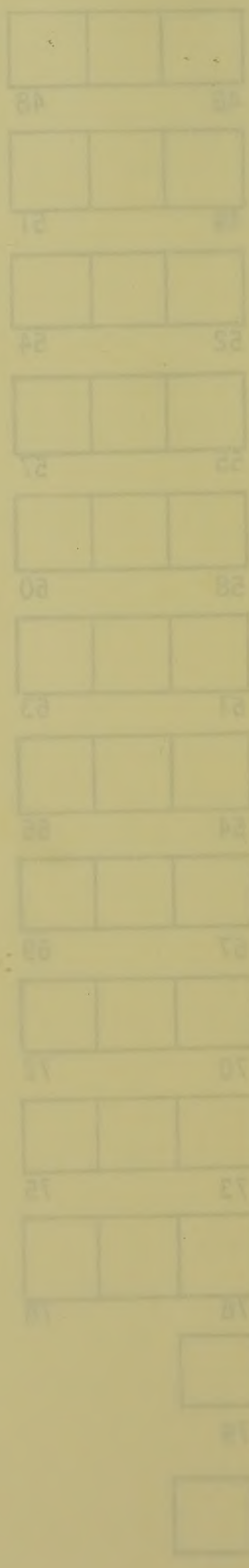
FRC 

CV 

N2 DIFF 

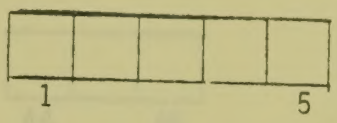
CODER

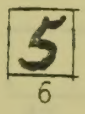
COLD

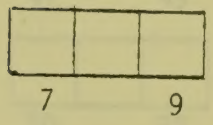


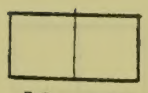
APPENDIX 4

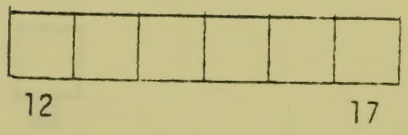
CHILDRENS' RESPIRATORY STUDY DATA CHECK CARD

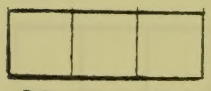
I.D. # 

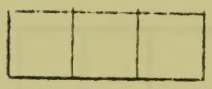
Card 

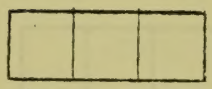
Height 

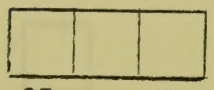
Age 

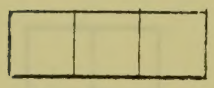
Test Date 

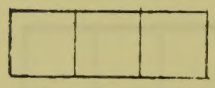
FVC 

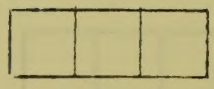
FEF 75-85 

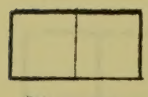
RV 

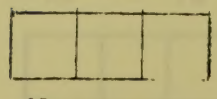
FRC 

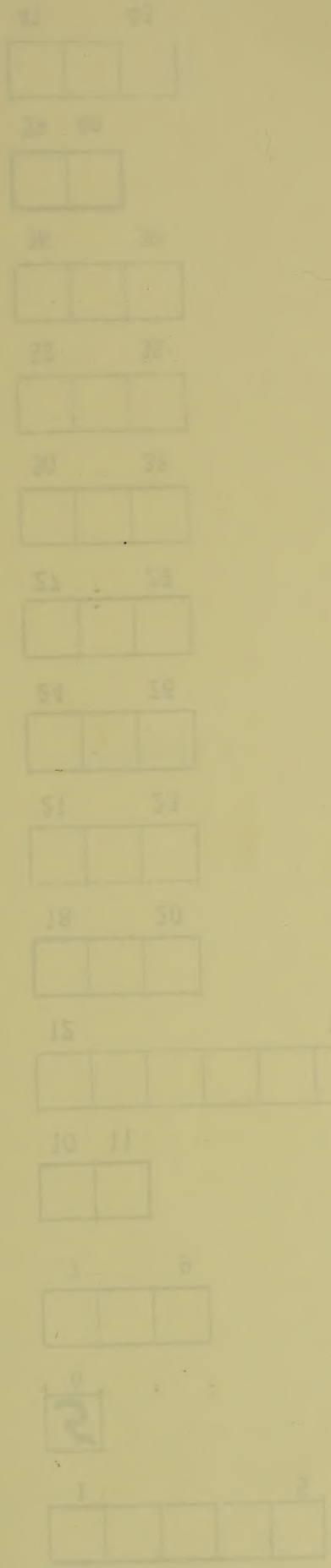
TLC 

ADS 

IDI 

CV Test CV 

TLC 



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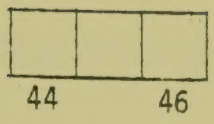

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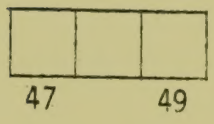
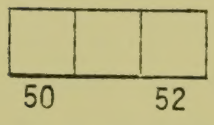


ΔN_2



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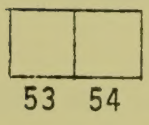
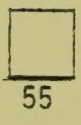


Corrected Volumes

Error Code



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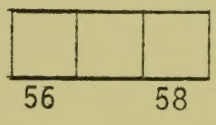

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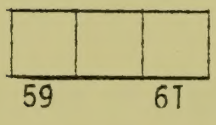

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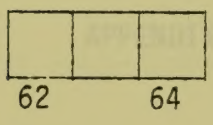
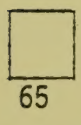


Corrected NW_5

Error Code



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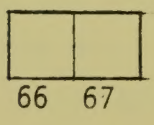

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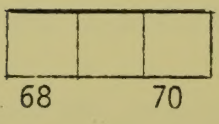

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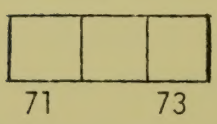
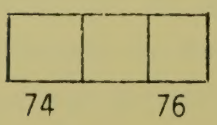
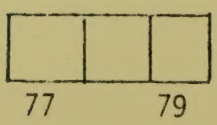


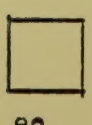
FRC



ΔN_2



Coder



APPENDIX 5

PROTOCOL AND CRITERIA FOR CODERS OF PULMONARY FUNCTION DATA

February 27, 1979

PROTOCOL

1. Each coder alternates schools day by day. When both coders have completed 20 tests each, a randomized quality control is done.

2. I.D. number, age, height and weight checked against slip. If there are any discrepancies - school called.

3. All values entered on coding forms if acceptable (see criteria).

CRITERIA

1. All VCs must be within 10% of biggest VC from all tests.

2. NWm: make sure that N2 concentration falls continuously to 1%.

3. FVC must be within 10% of biggest.

4. Spirometry - VC within 10% of biggest VC, FRC must be stable, i.e. volumes to be within 200 mls - (by eye). If machine has chosen incorrect FRC coders will correct this, recalculate ERV and IC and adjust RV and TLC values accordingly.

5. NWs - VC must be within 10% of biggest. Spirometry must look acceptable, i.e. a stable FRC and visible ERV/IC manoeuvre. If machine has picked the wrong slope for Phase III, the wrong beginning of Phase IV, or has incorrectly calculated the N2 difference, these will be remeasured and corrected by the coders. If two NWs tests are acceptable by all previous criteria and the VC's are within 5% of each other, all values are entered as the mean of the two tests.

6. Long reports are scrutinized. If requested by parents or if there are any indications of lung problems - they are given to Tony Kerigan.

7. Look at comments for appropriate coding of cold.

APPENDIX 6

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Point Monitoring of Ambient Concentrations of Atmospheric Gases Using Tunable Lasers

J. Reid
J. Shewchun
B. K. Garside
E. A. Ballik

Department of Engineering Physics and
Air Pollution Laboratory,
McMaster University, Hamilton, Ontario, Canada, L8S 4M1

Abstract

ser absorption spectrometer (LAS) is described which em- a wavelength tunable $Pb_{1-x}Sn_xSe$ laser diode in conjunc- with a multi-pass White cell. Absorption coefficients as low x 10^{-8} m^{-1} can be measured as a result of using a laser length modulation technique to suppress noise in the detec- system. This constitutes an improvement of several orders agnitude in sensitivity compared with earlier reported appli- ns of the direct absorption technique employing tunable e lasers. The performance of the LAS is illustrated by de- ing the measurement of three gases commonly found in the sphere: SO_2 and N_2O with sensitivities of 1 ppb, and NH_3 a sensitivity of better than 0.1 ppb. The linearity of re- se and calibration of the instrument are also discussed in detail.

I. Introduction

cal methods of identifying gases, and measuring their con- rations, have been used for many years.[1,2] In recent years, a deal of attention has been given to the use of lasers to itor air pollutants.[3] Much of this work has concentrated on cting molecular absorptions in the infrared, particularly long pathlengths through the atmosphere. In general, line- ble laser sources (CO_2, CO) have been employed to monitor e gases which have absorption lines in close coincidence the available output wavelengths of the lasers.[4-7] Some on long-path atmospheric absorption has also been re- ed using tunable diode lasers.[8,9] Both these techniques have n considerable success, but have been somewhat limited in tivity. To date, the minimum detectable absorption re- ed using such optical techniques is >0.1%.[8-11] Much greater rption sensitivities can be attained using acousto-optical niques,[12-15] but spectrophone cells are difficult to scale up ng pathlengths. In addition, this approach suffers from in- rence from unwanted molecular species,[16] and is somewhat cult to calibrate.[13,14] In the present paper, we describe a absorption spectrometer (LAS) which combines the sensi- of the acousto-optical methods with the convenience of t, long-path optical detection. In order to make the system exible as possible, it is based on wavelength-tunable Pb salt e lasers, which can be tailored to emit tunable radiation at elengths from 3 to 30 μm.[17] The beam from a diode laser is ed through a multi-pass White cell before detection. We have pathlengths from 1 to 300 m in the present system, which nsitive to absorption coefficients as small as 3 x 10^{-8} m^{-1}. sensitivity is two or three orders of magnitude better than attained by previous direct optical techniques, and is equiv- alent to that attained by the best acousto-optical systems.[13-15] An absorption coefficient of 3 x 10^{-8} m^{-1} corresponds to concentrations of 1 part per billion (ppb) of a weakly absorbing molecule such as SO_2 (ν_1 band), or 3 x 10^{-3} ppb of a strongly absorbing molecule such as CO. This sensitivity, combined with the wavelength tunability of diode lasers, permits trace amounts of almost any gaseous molecular species to be monitored. For example, the specific diode laser we have employed in the present work has the capability of detecting ambient levels of many gases commonly found in the atmosphere, such as SO_2, N_2O, H_2O, CO_2, NH_3 and O_3. Furthermore, our technique does not suffer from interferences from unwanted molecular species, and can be easily calibrated even at the ppb concentration level. The use of the LAS is illustrated by applying it to measurements of three gases: SO_2 and N_2O with a sensitivity of 1 ppb, and NH_3 with a sensitivity of better than 0.1 ppb. This paper constitutes a review of the work we have undertaken in the last year. As a consequence, some of the results described here have been reported elsewhere, and several figures are reproduced from a previous paper.[18]

Applications of the LAS include the continuous monitoring of ambient levels of most significant atmospheric gases, and the detection of traces of noxious gases in an industrial environment. The technique also shows promise for detecting the specific vapors given off by drugs or explosives. From a more fundamental point of view, the very high sensitivity and specificity of the technique can be exploited, for example, to measure very small values of absorption (or gain) in a discharge, determine molecular ion densities, and the populations of very highly excited molecules. The LAS also appears ideally suited for the optical isotope analysis methods described in recent papers.[19,20] Section II of this paper describes the detection techniques employed to measure very small absorptions. In Section III, we give results obtained with a 5 m White cell. Section IV details a novel procedure for calibrating the LAS in the ppb range, and for ensuring linearity of response. The final part of the paper, Section V, indicates the expected performance characteristics of a portable instrument, and describes some preliminary measurements made using a short 0.75 m White cell.

II. Experimental Apparatus and Detection Techniques

The diode laser used for the measurements reported in this paper is a $Pb_{1-x}Sn_xSe$ diode supplied by Laser Analytics. The particular composition of the ternary alloy (1% Sn) gives an output covering the range 1050 to 1180 cm^{-1}. The diode is mounted on the tip of a cold head, and cooled by a cryogenic He refrigerator. The temperature of this head can be set anywhere in the range 10-70 K and controlled at a given setting to within a few millidegrees. The choice of cold head temperature serves to determine the approximate laser emission wavelength. Fine tuning of this wavelength is obtained by varying the drive current supplied to the diode. When operated multi-mode, the

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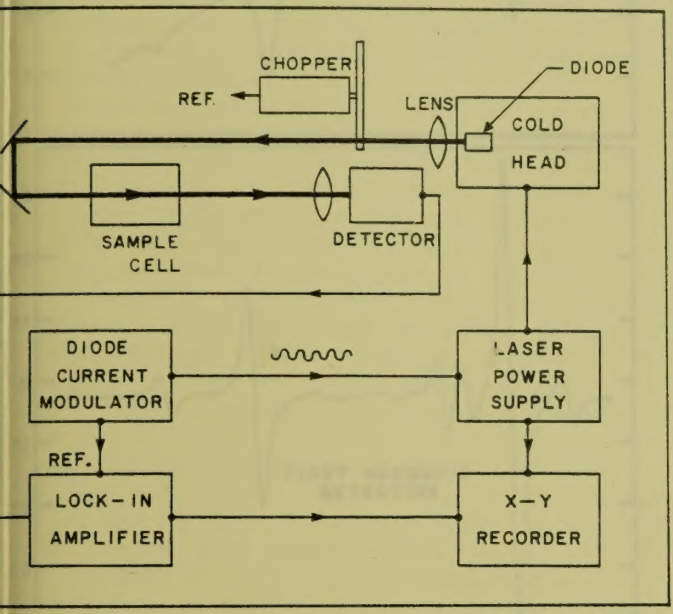
-109 received October 11, 1977.

ut power of the laser is in excess of 1 mW, but we generally tain the diode current close to threshold to ensure single e operation. Typical single mode powers are 100-200 μW. drive current supplied to the diode can be ramped to pro- a wavelength scan, and in addition a small high-frequency nt modulation can be superimposed. This results in a high- uency modulation (kHz range) of the diode wavelength, and this capability which enables us to achieve such high sensi- . For the initial stages of this work, the diode laser was as a high resolution spectrometer. The apparatus is illustra- schematically in Figure 1. The beam from the laser is fo-



re 1. Schematic diagram of the apparatus employing the diode laser igh resolution spectrometer.

d into a short sample cell, and the output is in turn focused a HgCdTe infrared detector. The laser beam can be chopped synchronously detected with a lock-in amplifier. The line- th of our laser is limited by thermal and mechanical fluctua- s, and is estimated to be less than 10 MHz. This linewidth is ower than the Doppler width of the gases under investiga- , and hence we operate with low pressures in the sample cell btain maximum resolution. The first step in the detection of gas is to determine the wavelength of the strong absorption s. As an example, we placed pure SO_2 in the sample cell at tal pressure of ∿10 Torr, and scanned those wavelength re- s covered by our diode laser. The lower trace in Figure 2 is cal of our experimental results. The diode wavelength was ed over ∿1 cm^{-1} using a combination of temperature and ent tuning. Throughout this wave-number region the diode operated in a single mode, thus eliminating the need for a de-selecting monochromator. The theoretical predictions of ugh[21] are shown in the upper half of Figure 2. In general, agreement between theory and experiment is good, with the dicted wave numbers rarely more than 0.01 cm^{-1} different n the experimental measurements. On the strong lines, the erimental intensities also agree with Clough's predictions to ter than 20%. Observe, however, that many weak SO_2 ab- ption lines (a few are indicated by *) are obtained experi- ntally which are not predicted from the theoretical compila- n.

The results shown in Figure 2 are typical of conventional n resolution spectra which can be obtained with tunable di- lasers.[21-23] We selected the two strong SO_2 lines near 2.0 cm^{-1} for more detailed study. They are shown on an ex- ded scale in the upper trace of Figure 3. While direct ampli- e traces of this nature are suitable for displaying strong ab-

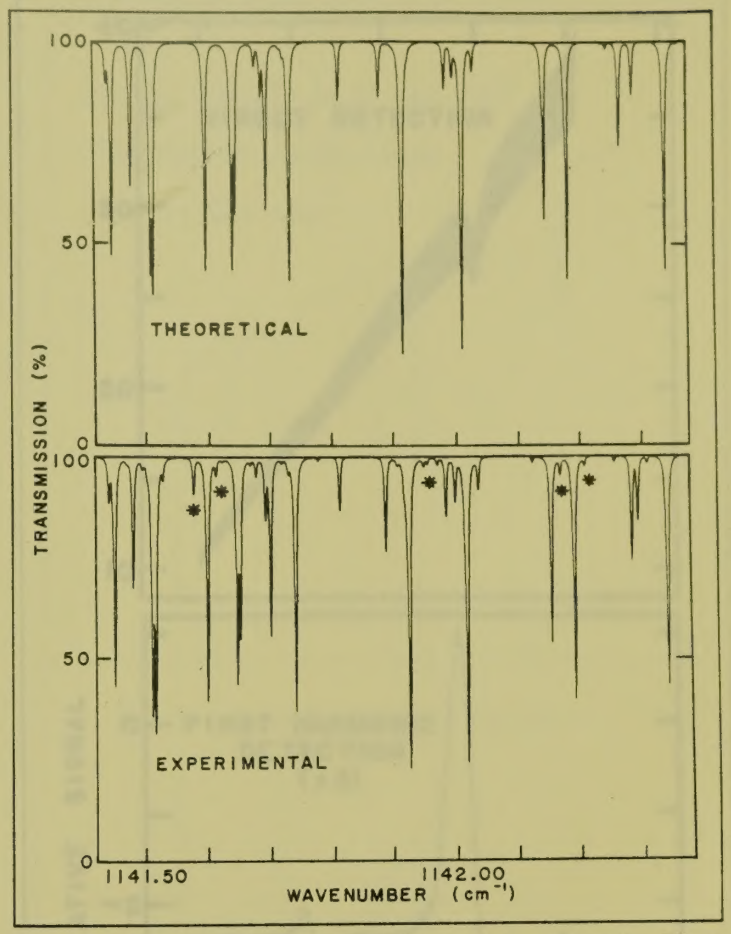
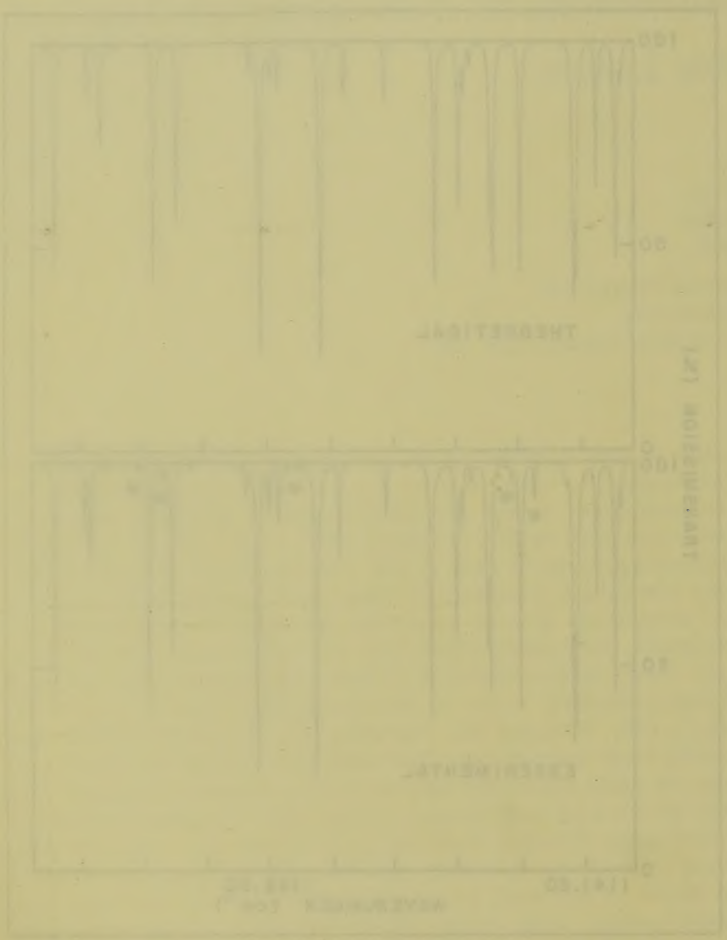
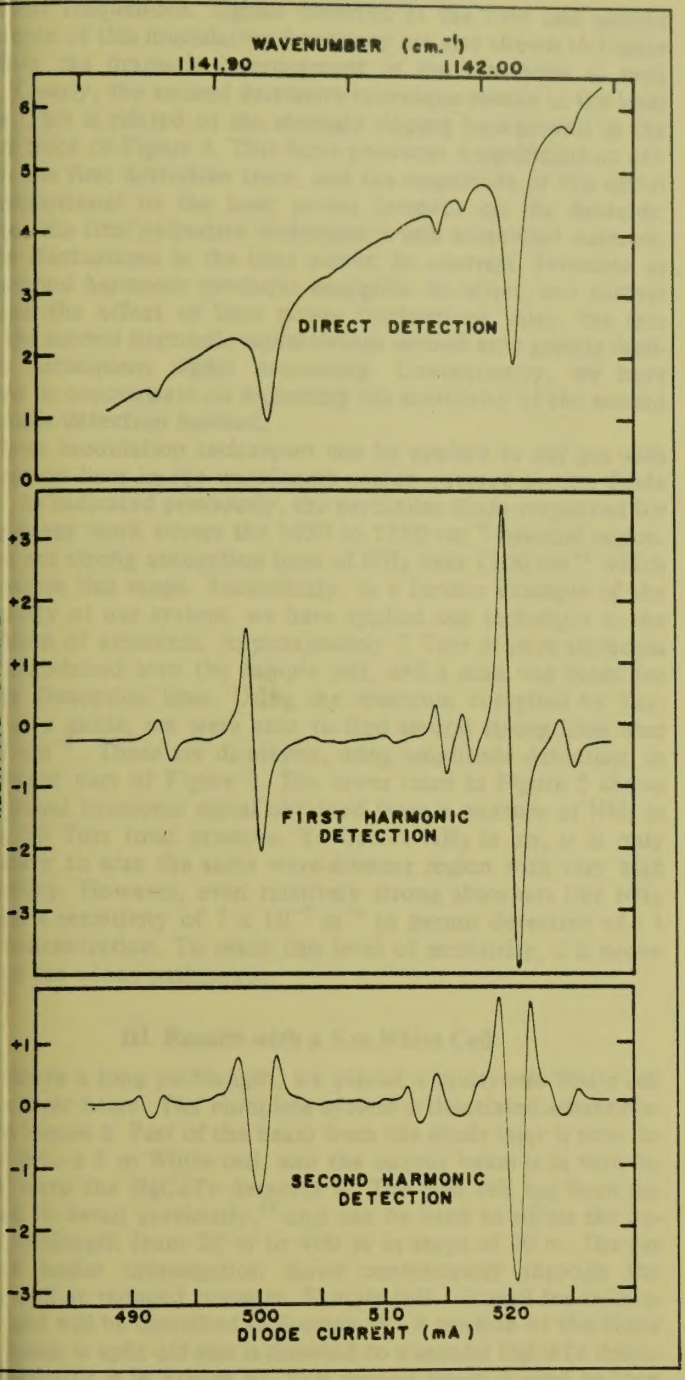


Figure 2. Experimental and theoretical transmission spectra for SO_2 in the 1142 cm^{-1} region. Many weak SO_2 absorption lines which are obtained experimentally are not predicted by the theoretical compilation of Clough;[21] a few of these are indicated by an asterisk.

sorption lines, the use of a mechanical chopper and direct detection was found to be a poor method of measuring very small absorptions. Accordingly, we investigated two alternative detection schemes. In each case the mechanical chopper is removed from the laser beam, and in its place the drive current to the diode is modulated at 1 kHz by an external signal generator, which also supplies the reference signal to the lock-in amplifier. The two lower traces in Figure 3 show the detector signals obtained at the first and second harmonic of this modulation frequency. In each case the modulation amplitude has been adjusted to give the largest signal, consistent with minimal broadening of the linewidth. This corresponds to a diode wavelength modulation of the order of the FWHM of the SO_2 absorption lines. Detection at the first and second harmonic of the modulation frequency is often referred to as taking the first and second derivative of the upper trace in Figure 3. However, a much smaller amplitude of modulation is required for a true derivative signal.[10] The three traces in Figure 3 were taken for identical absorption conditions, and are displayed on the same voltage scale. Note that the maximum excursion of the harmonic signals from zero is approximately equal to the magnitude of the direct absorption signal in the upper trace. This results from the fact that the direct absorption amplitude represents the maximum swing which can be obtained in a signal transmitted through the absorption cell. So, from this point of view, we neither lose nor gain signal by using the diode modulation technique.

The chief advantage of the modulation techniques is a dramatic reduction in the noise level. This is shown clearly in Figure 4, which represents several scans over two SO_2 lines in the 1141.9 cm^{-1} region. The SO_2/N_2 mixture used in the sample cell has been diluted with N_2, and the absorption at the stronger





ure 3. Three different SO_2 detection schemes. Upper trace — direct orption detection; middle trace — first harmonic detection; lower e — second harmonic detection. A 1 kHz diode current modulation is d for the harmonic detection.

e is only 10%. It can be seen that, for small absorptions, the ect amplitude detection method produces a very noisy trace. e chief source of this noise is power fluctuations in the laser m caused by mechanical vibrations of the diode, and con- uent beam wander in the optical path. For the purposes of ure 4, these power fluctuations have been enhanced by cing a small aperture in the beam path. The regular nature of "noise" is caused by the cycling of a piston in the diode d head. It is obvious that direct detection techniques using chanical choppers are very susceptible to any type of power ctuations in the laser beam. Other disadvantages of this tech- ue are the strongly sloping background signal, which make it y difficult to identify small absorptions, and the vulnerability the scheme to small drifts in the laser output power. All these blems can be avoided by modulating the diode current at

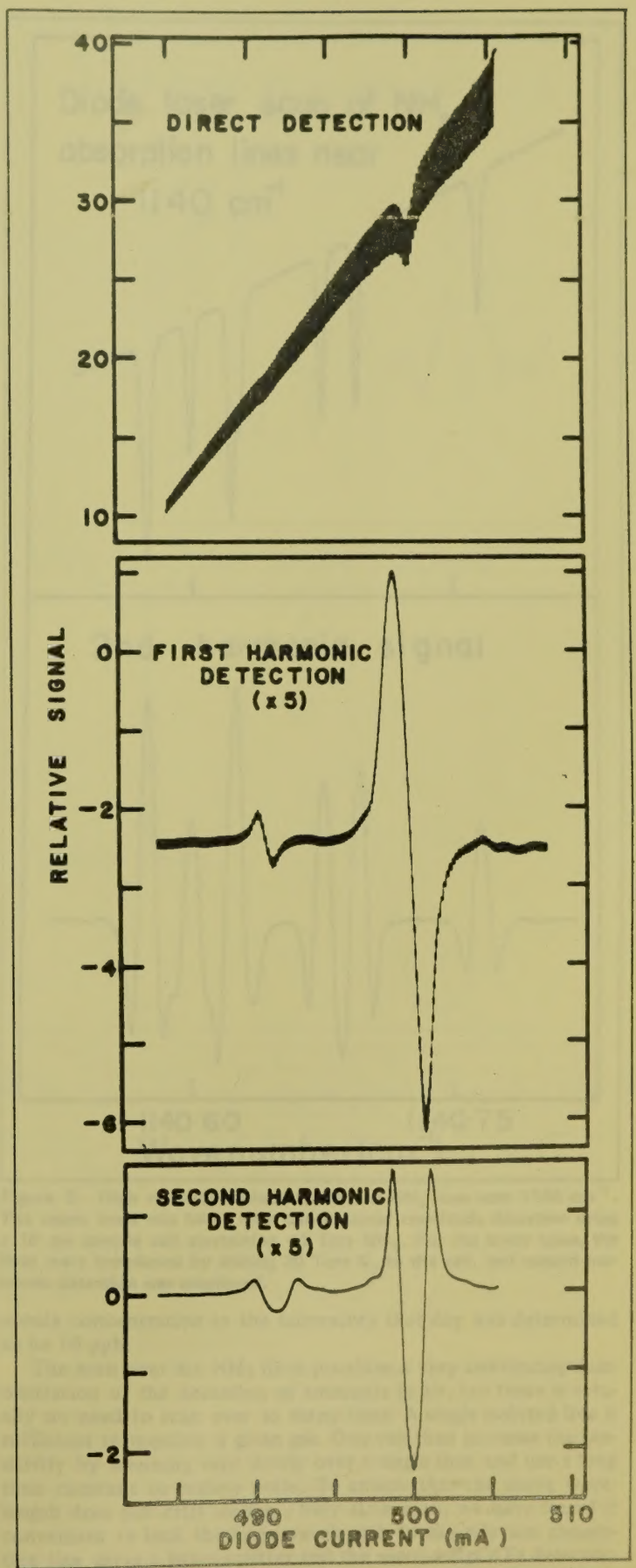
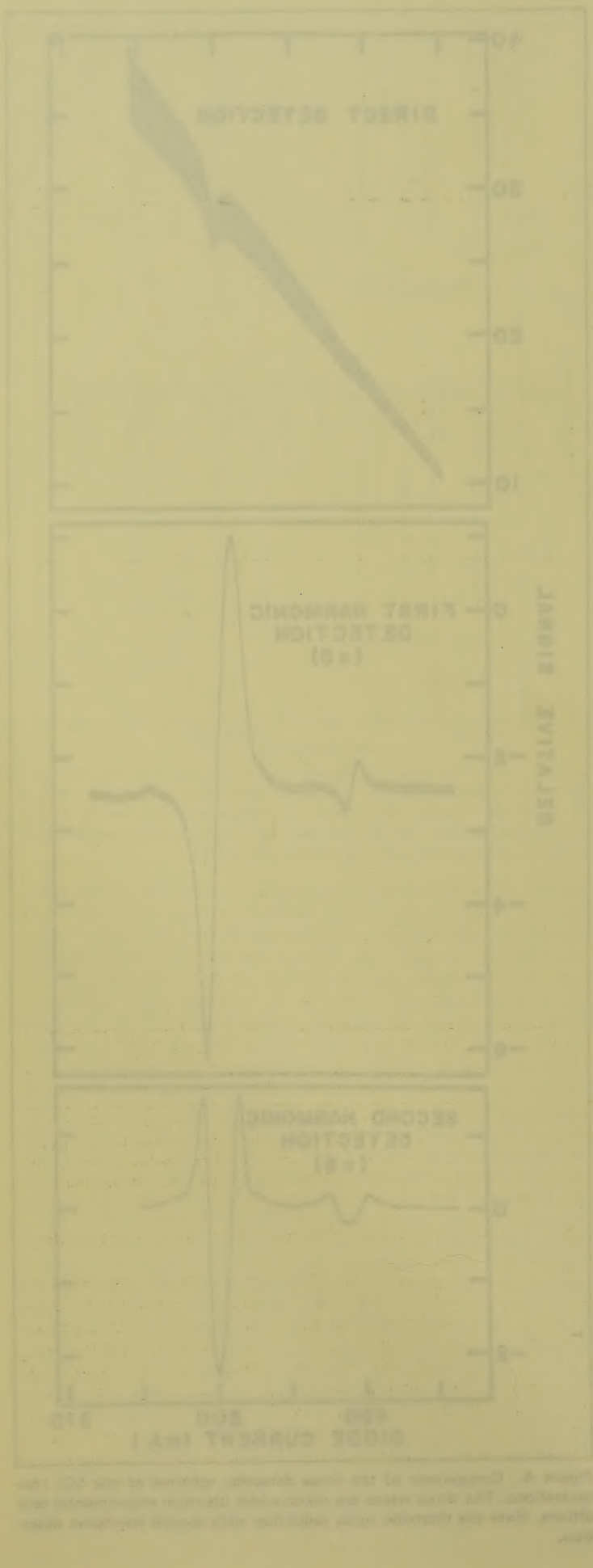
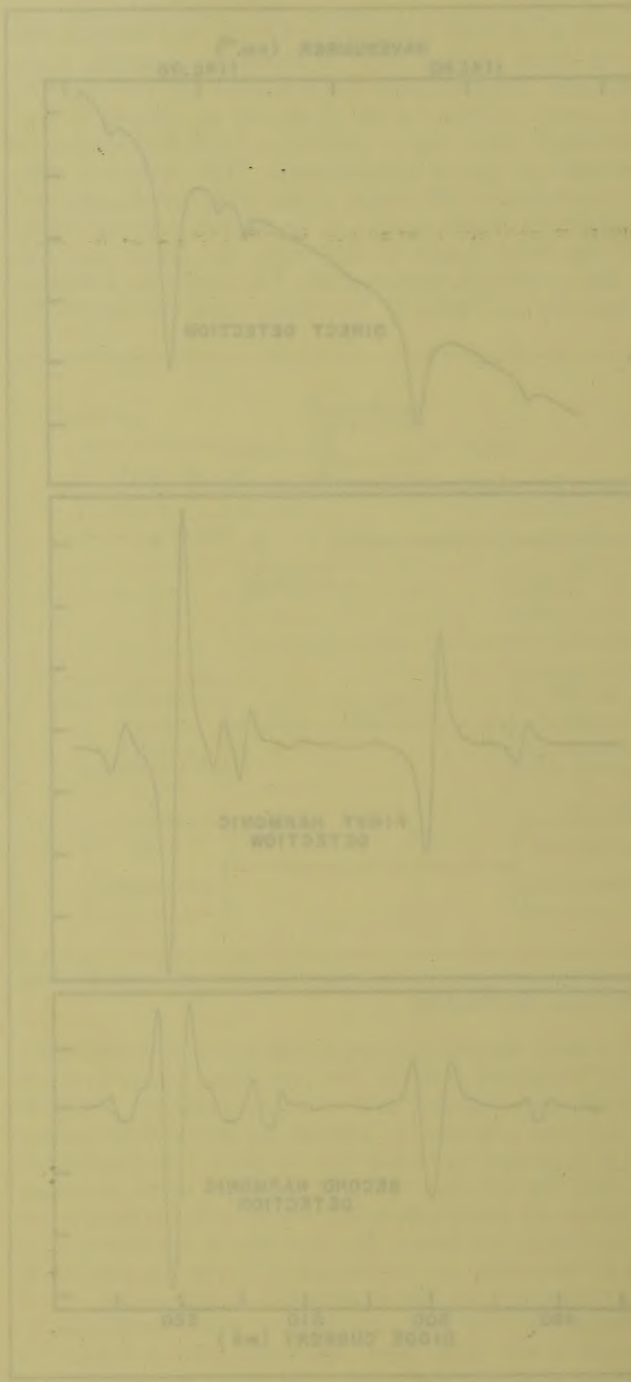


Figure 4. Comparison of the three detection schemes at low SO_2 concentrations. The three traces are taken under identical experimental conditions. Note the dramatic noise reduction with second harmonic detection.


DIRECT DETECTION
FIRST HARMONIC DETECTION (x 5)
SECOND HARMONIC DETECTION (x 5)
RELATIVE SIGNAL
DIODE CURRENT (mA)


DIRECT DETECTION
FIRST HARMONIC DETECTION
SECOND HARMONIC DETECTION
DIODE CURRENT (mA)

hertz frequencies. Signals detected at the first and second nonic of this modulation frequency are also shown in Figure Note the dramatic improvement in signal-to-noise at each . Clearly, the second derivative technique results in the least e. This is related to the strongly sloping background in the er trace of Figure 4. This slope produces a significant dc off- n the first derivative trace, and the magnitude of this offset roportional to the laser power incident on the detector. ce, the first derivative technique is still somewhat susceptito fluctuations in the laser power. In contrast, detection at second harmonic produces negligible dc offset, and further ces the effect of laser power fluctuations. Also, the fact the second harmonic signal swings around zero greatly facil- s subsequent signal processing. Consequently, we have en to concentrate on increasing the sensitivity of the second nonic detection method.

hese modulation techniques can be applied to any gas with rption lines in the wavelength region covered by the diode . As indicated previously, the particular diode employed for present work covers the 1050 to 1180 cm^{-1} spectral region. re are strong absorption lines of NH_3 near 1100 cm^{-1} which within this range. Accordingly, as a further example of the tility of our system, we have applied our technique to the ction of ammonia. Approximately 1 Torr of pure ammonia introduced into the sample cell, and a scan was made for ng absorption lines. Using the spectrum compiled by Tay- as a guide, we were able to find several strong lines near) cm^{-1}. These are displayed, using amplitude detection, in upper part of Figure 5. The lower trace in Figure 5 shows second harmonic signal obtained from a mixture of NH_3 in t 20 Torr total pressure. To detect NH_3 in air, it is only ssary to scan the same wave-number region with very high itivity. However, even relatively strong absorbers like NH_3 ire a sensitivity of 7×10^{-7} m^{-1} to permit detection of a 1 concentration. To reach this level of sensitivity, it is neces- to use a long pathlength.

III. Results with a 5 m White Cell

chieve a long pathlength, we placed a multi-pass White cell e laser beam. The complete system is illustrated schematicn Figure 6. Part of the beam from the diode laser is now fod into a 5 m White cell, and the output beam is in turn fod onto the HgCdTe detector A. The 5 m cell has been ded in detail previously,[25] and can be used to adjust the op- pathlength from 20 m to 400 m in steps of 20 m. The gas le under investigation flows continuously through the e cell at reduced pressure. Sample cell 1 is used for calibra- and will be described in Section IV. A portion of the diode beam is split off and is directed to a second HgCdTe detec- Detector B in Figure 6). This second beam is used to lock aser wavelength to the molecular absorption line under ingation, as described later in this section.

he optical system indicated in Figure 6 was carefully de- d to minimize scattered and reflected beams in the optical . Interferences between such beams tend to produce a series abry-Perot fringes as the diode wavelength is tuned.[18] We succeeded in reducing such fringes to a level $< 10^{-5}$ of the t power, but they are still the limiting factor in the sensitivf the present system. Figure 7 is typical of the results ob- d with the 5 m White cell. The cell is set for a 200 m path- h, and air at 20 Torr pressure flows through it. The diode is scanned over the same wavelength region as in Figure 5, the upper trace shows the second harmonic signal obtained detector A. This scan clearly illustrates the capability of AS to detect ammonia in air. There are two additional abtion lines present in this air scan. These were identified as P(34) ($02^{\circ}0 - 00^{\circ}0$) and the P(24)D ($03^{1}0 - 01^{1}0$) lines of at 1140.606 cm^{-1} and 1140.747 cm^{-1}, respectively.[26] g the calibration procedures outlined in Section IV, the am-

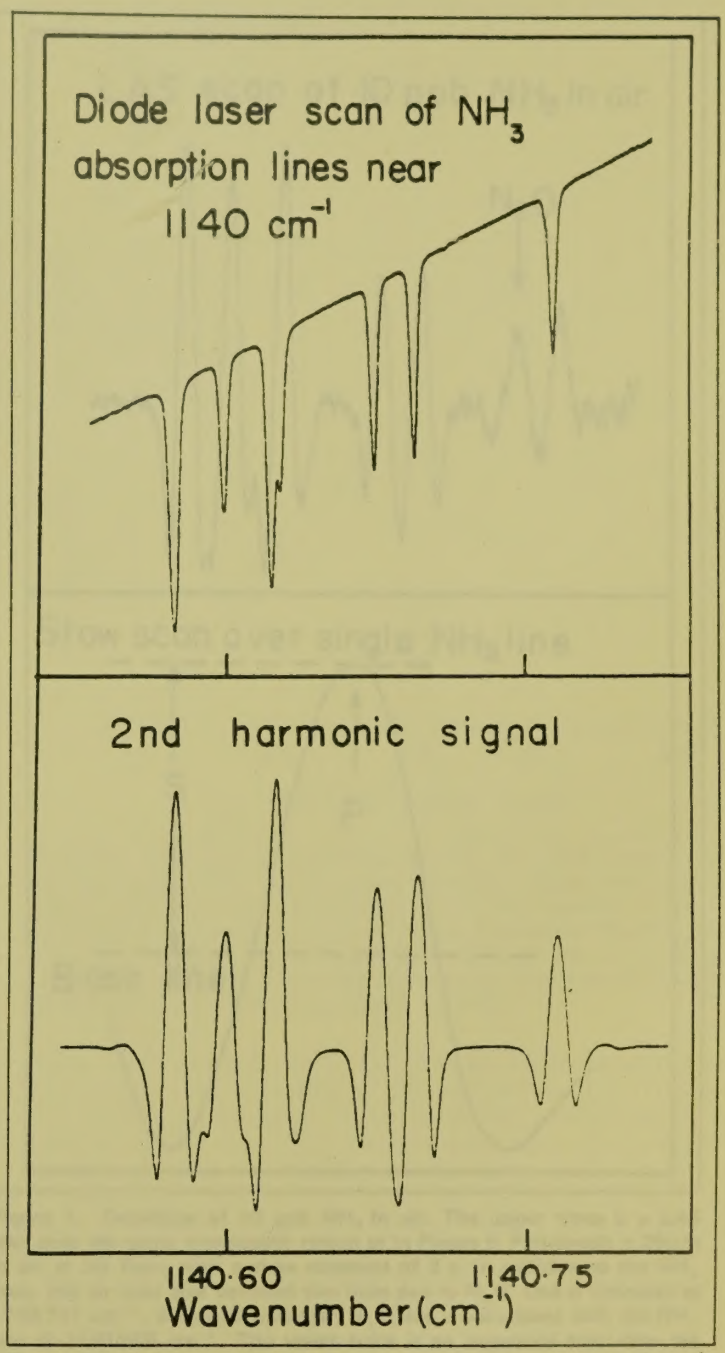
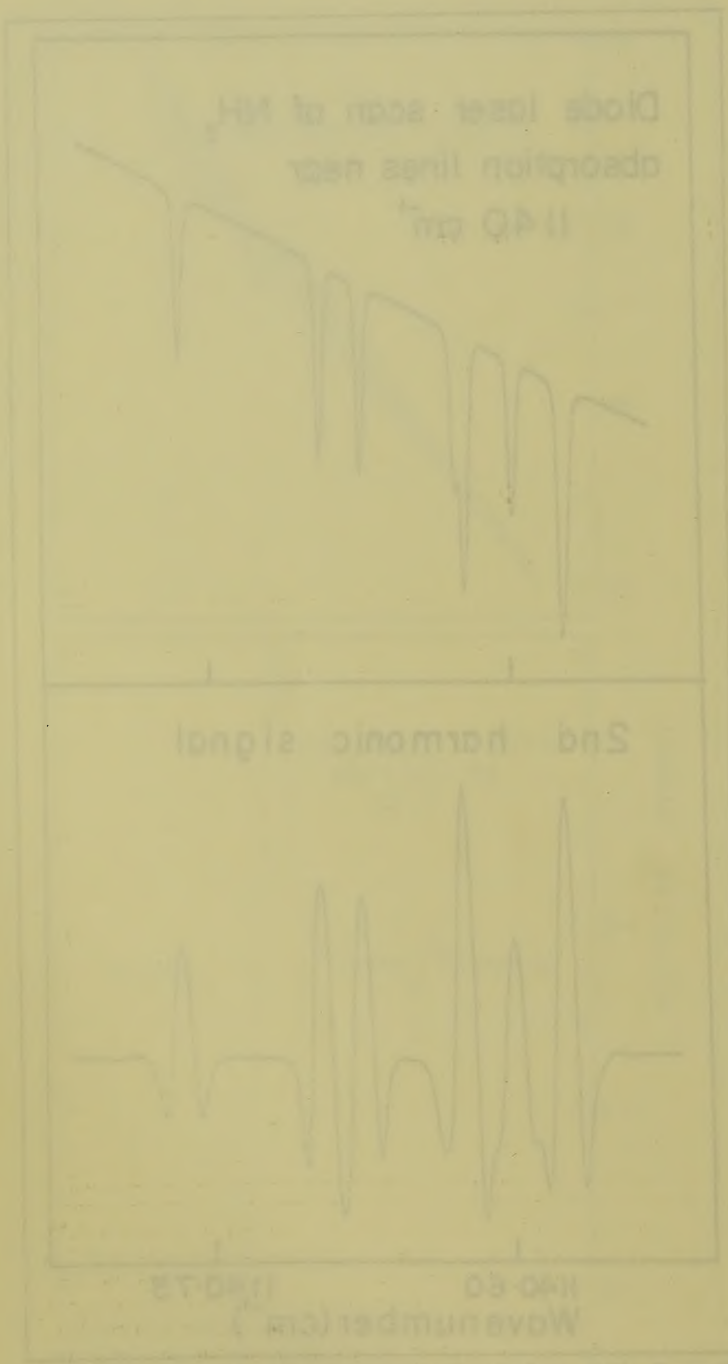
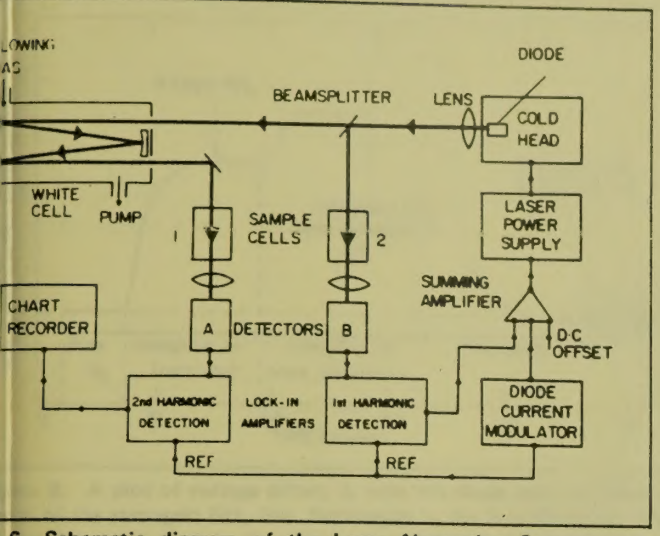


Figure 5. High resolution diode spectra of NH_3 lines near 1140 cm^{-1}. The upper trace was taken with conventional amplitude detection using a 10 cm sample cell containing <1 Torr NH_3. For the lower trace, the lines were broadened by adding 20 Torr N_2 to the cell, and second harmonic detection was employed.

monia concentration in the laboratory that day was determined to be 10 ppb.

The scan over six NH_3 lines provides a very convincing demonstration of the detection of ammonia in air, but there is actually no need to scan over so many lines. A single isolated line is sufficient to monitor a given gas. One can then increase the sensitivity by scanning very slowly over a single line, and use a long time constant to reduce noise. To ensure that the diode wavelength does not drift during a very slow scan, we have found it convenient to lock the laser wavelength to the relevant absorption line using a beam splitter and the second HgCdTe detector. A short cell (cell 2 of Figure 6) containing pure ammonia at low pressure is placed in this beam, and first harmonic detection is used to give a derivative lineshape. The laser wavelength is then locked to line center using conventional servo techniques. The


Diode laser scan of NH3
absorption lines near
1149 cm-1
2nd harmonic signal
1150.60
1150.73
Wavenumber (cm-1)



6. Schematic diagram of the Laser Absorption Spectrometer used to monitor ambient concentrations of atmospheric gases.

ength can be scanned by introducing a slow dc ramp into edback loop. This dc offset shifts the locking point from enter, and allows one to scan slowly from one edge of the o the other. The lower trace in Figure 7 shows a typical vhen locked to the strongest NH_3 line at 1140.58 cm^{-1}. e constant of 10 s was used for this trace. Under these ions we estimate the noise level to correspond to an ab-on coefficient of 6×10^{-8} m^{-1} (0.1 ppb NH_3). takes several minutes to complete the expanded scan in Figure 7. A more effective utilization of this time is to lock at point P, and measure the voltage offset, S, the baseline. In this manner one can conveniently use time nts as long as 100 s, and continuously monitor changing of gas concentration. Naturally, before selecting a particu-olecular absorption line, a direct check is made to ensure here are no interfering absorptions from other molecules t in the gas sample. Such interferences are rarely a prob-as the LAS is operated at low pressures where the line-s are close to the Doppler-limit. Another advantage of g the laser wavelength using a short cell of pure gas is that firms the identification of the absorption line being mea-in the air. We have locked to isolated lines in NH_3, SO_2 $_2O$ (using detector B and the relevant gas in cell 2), while oring the same absorption lines in air using detector A. s obtained while monitoring NH_3 are shown in Figure 8. iode laser is locked to the center of an NH_3 absorption nd the second harmonic signal at detector A is recorded art paper as the gas mixture in the 5 m White cell is varied. aseline level is obtained by flowing a gas containing no pure N_2 in this case), or simply by evacuating the cell. that when the LAS was sampling laboratory air, a some-higher reading was obtained due to NH_3 given off by lab-y personnel. If anyone stood close to the air intake tube, H_3 emitted by the human body would drive the LAS off as can clearly be seen in Figure 8. No particular care was to eliminate the influence of such effects from the mea-ents taken of the local atmosphere. The LAS response was ated using a known NH_3 in N_2 mixture (see Section IV). race shown in Figure 8 was taken with a time constant of , and the noise level corresponds to an absorption coef-: of 3×10^{-8} cm^{-1}, or less than 0.1 ppb NH_3. These re-re typical of the day-to-day operation of the instrument. ve monitored atmospheric NH_3, SO_2, and N_2O concentra-for periods of several hours at a time, and the diode laser en in trouble-free operation for many months. To change one gas to another, the diode temperature and current are ed slightly to shift to the correct wavelength, and the gas

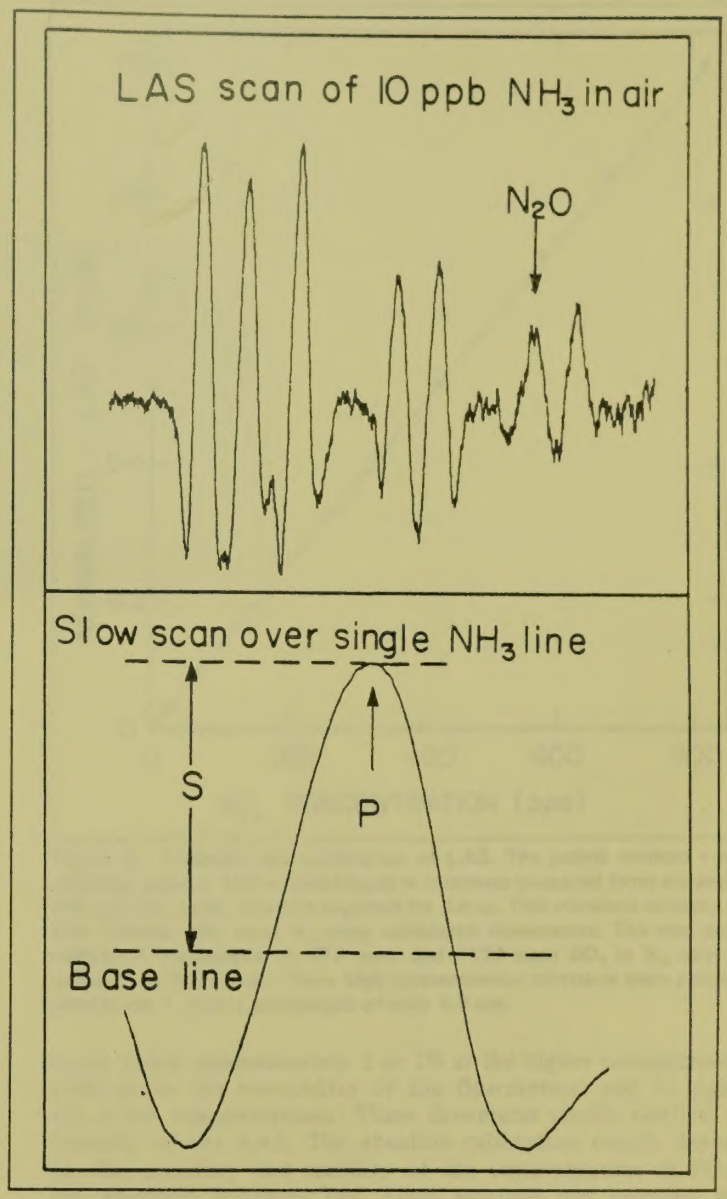
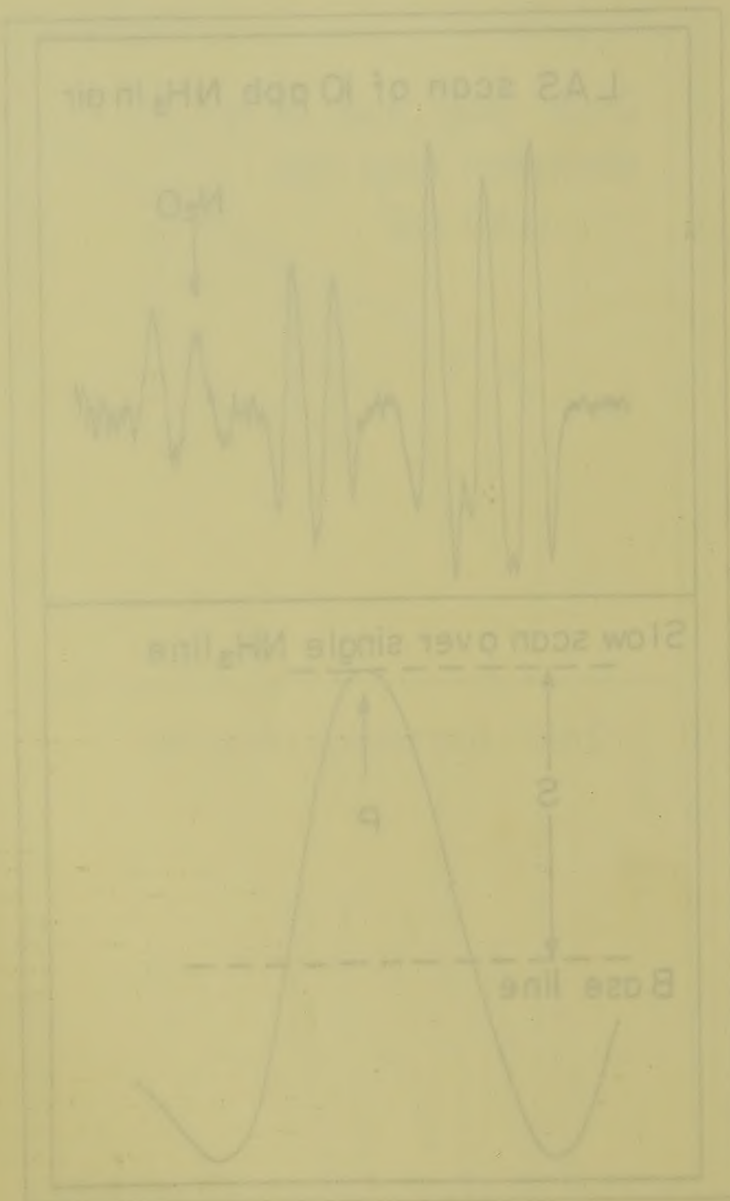
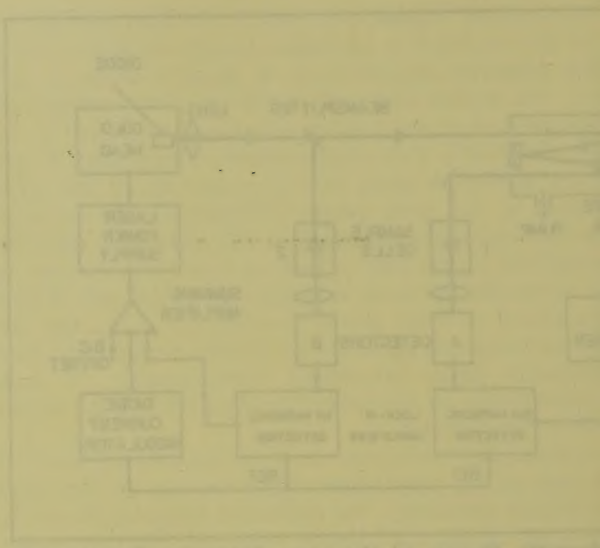


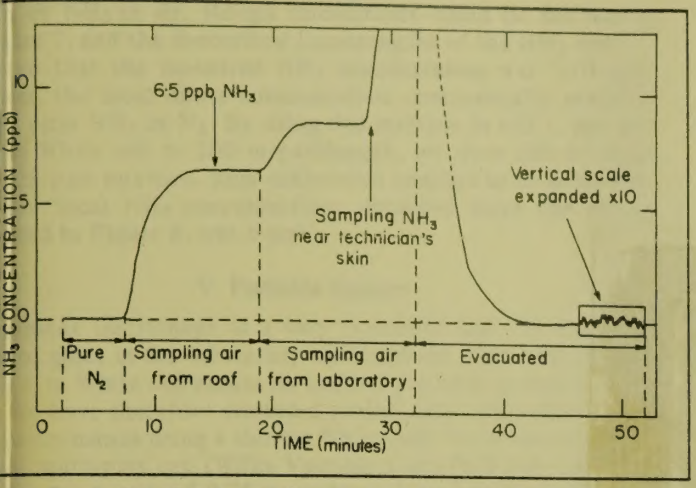
Figure 7. Detection of 10 ppb NH_3 in air. The upper trace is a LAS scan over the same wavelength region as in Figure 5. Pathlength is 200 m in air at 20 Torr, with a time constant of 3 s. In addition to the NH_3 lines, the air scan also contains two lines due to N_2O. One is indicated at 1140.747 cm^{-1}. A second, stronger, N_2O line is coincident with the NH_3 line at 1140.606 cm^{-1}. The lower trace is an expanded scan over the strongest NH_3 line ($\sim$1140.58 cm^{-1}), taken with a time constant of 10 s.

in sample cell 2 is changed. N_2O was monitored on the overlapping P(28) ($02^{\circ}0 - 00^{\circ}0$) and the P(18)C ($03^{1}0 - 01^{1}0$) lines at 1145.334 cm^{-1},[26] with a sensitivity of $\sim$1 ppb. SO_2 was monitored on several different lines in the 1140 to 1145 cm^{-1} region, with a similar sensitivity.

The particular absorption lines used to monitor NH_3, N_2O and SO_2 are by no means the strongest available, if the range is not restricted to that covered by the present diode. For example, the sensitivity to SO_2 can be increased ten times by using the stronger ν_3 absorption lines in the 7.3 μm region. The LAS approach to pollution monitoring is extremely flexible. In principle, we can detect any gas with absorption lines in the infrared (3 to 30 μm region) using Pb salt diode lasers. Table 1 shows a sample of the molecules we can detect with the diode used in our present work. We also include in Table 1 other molecules of atmospheric interest which can be detected using additional diode lasers operating in other wavelength regions. No attempt has been made to be exhaustive in this listing, and the sensitivities


LAS scan of 10 ppb NH3 in air
H2O
Slow scan over single NH3 line
P
S
Base line





gure 8. A plot of voltage offset, S, with the diode laser locked at the nter of the strongest NH_3 line. Pathlength in the 5 m White cell is 200 and the gas mixture in the cell is varied with time. Under these condi-ns, the speed of response of the LAS is limited by the 100 s time con-nt used with lock-in amplifier A. Note that the LAS reading is strongly fected by the proximity of laboratory personnel to the gas sampling in-ke.

Table 1. Minimum detectable concentration for many molecules of atmospheric importance. The results are quoted for the sensitivity achieved with the 5 m White cell, i.e., 3 x 10^{-8} m^{-1}.

olecule	Absorption Coefficient of Strong Lines (m^{-1} ppb^{-1})	Approximate Wavenumber of lines (cm^{-1})	Sensitivity (ppb)	
SO_2	3.5 x 10^{-8}	1140	1	Observed
N_2O	3 x 10^{-8}	1145	1	Experimentally
NH_3	7 x 10^{-7}	1140	0.05	
O_3	2 x 10^{-7}	1050	0.2	Present
CO_2	3.5 x 10^{-10}	1075	100	Diode
H_2O	2 x 10^{-9}	1135	15	Range
PAN	∼3 x 10^{-7}	1150	∼0.1	
CH_4	3 x 10^{-6}	1300	0.01	
SO_2	3.5 x 10^{-7}	1370	0.1	
NO_2	5 x 10^{-6}	1600	0.006	Additional Diodes
NO	3 x 10^{-6}	1880	0.01	
CO	1 x 10^{-5}	2120	0.003	
CO_2	3 x 10^{-5}	2350	0.001	

ioted are equivalent to those achieved with the present system. ; the gases are measured at low pressure, there is no need to oid wavelength regions where strong water vapor absorption curs.

IV. Linearity and Calibration

n important property of any practical pollution monitoring strument is that its response should be linear, and that it ould be easily calibrated. The LAS is based on the measure-ent of optical absorption, and for the very small optical den-ies involved, Beer's Law should ensure linearity of response. evertheless, this linearity was checked under practical condi-ns. The diode laser was locked to an SO_2 absorption line, and libratd SO_2 in N_2 mixtures were passed through the White ll. The results are shown in Figure 9. The calibrated mixtures ere prepared from an 820 ppb SO_2 in N_2 mixture supplied by rco Industrial Gases. This standard mixture was then diluted th pure N_2 using a carefully calibrated flowmeter system. ithin experimental error, the LAS response was linear over the tire range from 20 to 820 ppb. The experimental error was

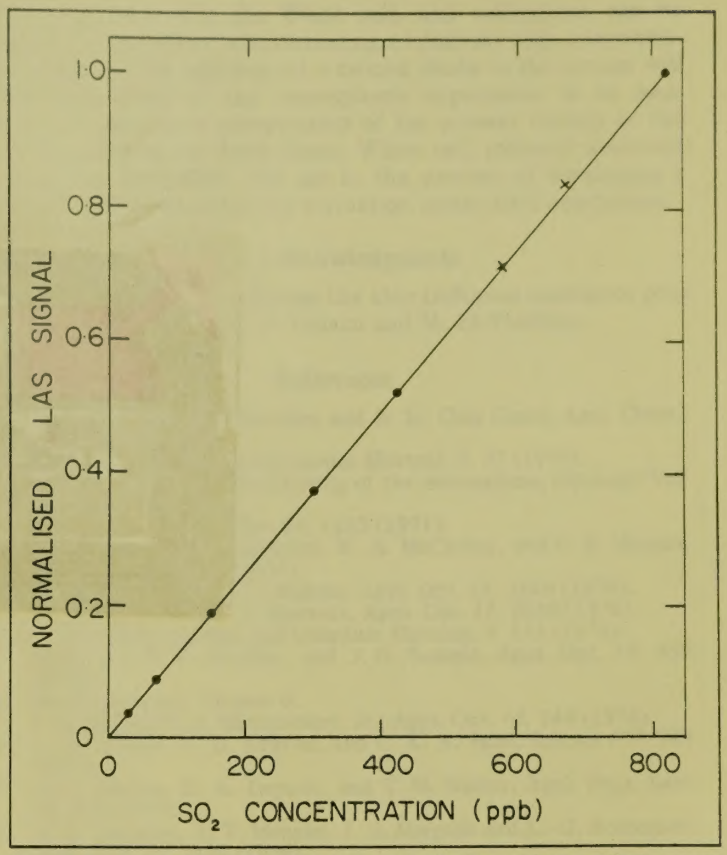


Figure 9. Linearity and calibration of LAS. The points marked • were obtained using a 160 m pathlength in mixtures prepared from a standard 820 ppb SO_2 in N_2 mixture supplied by Airco. This standard mixture was then diluted with pure N_2 using calibrated flowmeters. The two points marked X correspond to 973 ppm and 1123 ppm SO_2 in N_2 mixtures supplied by Matheson. These high concentration mixtures were placed in sample cell 1, with a pathlength of only 9.5 cm.

small, being approximately 1 or 2% at the higher concentrations (limited by the resetability of the flowmeters) and ±1 ppb at the lower concentrations. These flowmeter results confirm the linearity of the LAS. The absolute calibration clearly depends on the accuracy and stability of the concentration of SO_2 in the standard mixture. The Airco mixture was supplied in a specially coated aluminum cylinder designed to minimize concentration changes with time and temperature.[27] Nevertheless, SO_2 mixtures in the ppb range are notoriously difficult to prepare and store, and an independent check on the calibration is in order. Fortunately, the LAS can be directly calibrated for mixtures in the ppb range using high SO_2 concentration mixtures which do not suffer from the same preparation and storage problems. Over an interval of several months, two cylinders of ∼1000 parts per *million* SO_2 in N_2 were obtained from Matheson Gas Products. These mixtures were passed, at the same pressure as in the multi-pass cell, through a 10 cm cell placed in front of the 5 m White cell (cell 1 in Figure 1). With the White cell set for a 160 m pathlength, the LAS response is equivalent to a mixture of ∼625 parts per *billion* flowing through the White cell.[28] These results are also indicated on Figure 9. The very good agreement obtained with mixtures from two different suppliers, and differing in nominal concentration by 3 orders of magnitude, confirms the absolute calibration of the LAS for the monitoring of SO_2. In principle, one could even eliminate the necessity of obtaining calibrated mixtures by making a one-time measurement of the linestrength and linewidths of the relevant absorption lines in *pure* SO_2, i.e., the LAS can be entirely calibrated by optical methods.

The usefulness of these calibration techniques was particularly well illustrated when we attempted to measure the concen-

n of NH_3 in air. Rough calculations based on the results gure 7, and the theoretical linestrengths of the NH_3 lines,[24] ated that the measured NH_3 concentration was ∿10 ppb. ever, the most dilute concentration commercially available 0 ppm NH_3 in N_2. By using this mixture in cell 1, and set- he White cell to 200 m pathlength, we were able to simu- 25 ppb mixture. This calibration enabled us to determine the local NH_3 concentration, obtained from the results rated in Figure 8, was 6 ppb.

V. Portable System

present instrument is a very powerful tool for detecting s of gases in the laboratory environment. However, the size e 5 m White cell makes its use as a portable system impracWe have therefore started a preliminary evaluation of the performance using a shorter White cell. We obtained a comial multi-pass cell (Wilks Variable Long Path Gas Cell) with gle pass length of 0.75 m, and capable of pathlengths up to . This cell was operated with a total pathlength of 40.5 m. initial results are very encouraging. Despite a reduction in ength of a factor of 7 compared with the 5 m cell, we find etter mechanical stability of the Wilks cell results in a reion in sensitivity by a factor of 3 or 4. The present sensitivf the LAS using the short Wilks cell is ∿5 ppb SO_2 or N_2O ∿0.2 ppb NH_3. These figures apply to continuous monitorvith a 100 s time constant, and correspond to absorption ficients $\sim 10^{-7}$ m^{-1}. This sensitivity is still limited by interce fringes formed by components in the optical path. An ase of sensitivity by at least two orders of magnitude is ble before the theoretical limit set by detector noise is ed.[18, 29] We are currently working towards eliminating e of these residual interference effects, and hope to further ase the sensitivity of the LAS using the Wilks cell.

VI. Conclusions

ser absorption spectrometer has been described which has ed capable of detecting absorption coefficients as low as 10^{-8} m^{-1} on a routine basis. This very high sensitivity, toer with the wavelength tunability of the diode laser, permits detection of most atmospheric gases with a sensitivity of er than 1 ppb. The present capability of the LAS, even n used in conjunction with a relatively small absorption nber, is more than adequate for many practical atmospheric itoring applications. However, the sensitivity still falls far t of the limiting value determined by detector noise, and e is considerable scope for further improvement.

n principle, the use of Pb salt tunable diode lasers permits detection of any gas having absorption lines in the 3 - 30 μm e. The diode we have employed for the present work operfrom 1050 to 1180 cm^{-1} and has been used to demonstrate detection of atmospheric concentrations of SO_2, N_2O and . The particular absorption lines selected for each gas were trained to lie within the tuning range of the diode, and are o means the strongest absorption lines of these molecules.

n its present mode of operation, the LAS is well suited for as a continuous pollution monitor. The instrument can be zeroed by evacuating the White cell, and calibration can be checked using a short cell containing a relatively high concentration mixture. The addition of a second diode to the system will allow most gases of any atmospheric importance to be measured. All the major components of the present version of the LAS are commercial items (laser, White cell, infrared detectors and lock-in amplifiers). We are in the process of developing a fully portable instrument for evaluation under field conditions.

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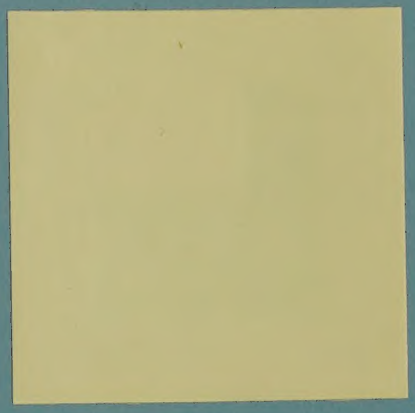
References

1. R. H. Pierson, A. N. Fletcher, and E. St. Clair Gantz, Anal. Chem., *28*, 1218 (1956).
2. P. L. Hanst, Optical and Quantum Electron. *8*, 87 (1976).
3. E. D. Hinkley, Laser Monitoring of the Atmosphere, (Springer-Verlag, New York, 1976).
4. R. T. Menzies, Appl. Opt. *10*, 1532 (1971).
5. R. R. Patty, G. M. Russwurm, W. A. McClenny, and D. R. Morgan, Appl. Opt. *13*, 2850 (1974).
6. R. T. Menzies and M. T. Chahine, Appl. Opt. *13*, 2840 (1974).
7. R. T. Menzies and M. S. Shumate, Appl. Opt. *15*, 2080 (1976).
8. E. D. Hinkley, Optical and Quantum Electron. *8*, 155 (1976).
9. R. T. Ku, E. D. Hinkley, and J. O. Sample, Appl. Opt. *14*, 854 (1975).
10. See Reference 3, Chapter 6.
11. J. C. Hill and G. P. Montgomery, Jr., Appl. Opt. *15*, 748 (1976).
12. L. B. Kreuzer, N. D. Kenyon, and C. K. N. Patel, Science *177*, 347 (1972).
13. T. F. Deaton, D. A. Depatie, and T. W. Walker, Appl. Phys. Lett. *26*, 300 (1975).
14. M. S. Shumate, R. T. Menzies, J. S. Margolis and L. -G. Rosengren, Appl. Opt. *15*, 2480 (1976).
15. C. K. N. Patel and R. J. Kerl, Appl. Phys. Lett. *30*, 578 (1977).
16. J. C. Peterson, R. J. Nordstrom, and R. K. Long, Appl. Opt. *15*, 2974 (1976).
17. Laser Analytics offer a range of commercial diode lasers which are wavelength selectable from 2.7 to 30 μm.
18. J. Reid, J. Shewchun, B. K. Garside, and E. A. Ballik, "High sensitivity pollution detection employing tunable diode lasers," Appl. Opt., to be published.
19. B. Lehmann, M. Wahlen, R. Zumbrunn, and H. Oeschger, Appl. Phys. *13*, 153 (1977).
20. M. Wahlen, R. S. Eng, and K. W. Nill, Appl. Opt. *16*, 2350 (1977).
21. E. D. Hinkley, A. R. Calawa, P. L. Kelly and S. A. Clough, J. Appl. Phys. *43*, 3222 (1972).
22. G. P. Montgomery, Jr. and J. C. Hill, J. Opt Soc. Am. *65*, 579 (1975).
23. J. S. Knoll, G. L. Tettemer, W. G. Planet, K. Narahari Rao, Da-Wun Chen, and L. A. Pugh, Appl. Opt. *15*, 2973 (1976).
24. F. W. Taylor, J. Quant. Spectrosc. Radiat. Transfer, *13*, 1181 (1973).
25. J. Shewchun, B. K. Garside, E. A. Ballik, C. C. Y. Kwan, M. M. El-Sherbiny, G. Hogenkamp, and A. Kazandjian, Appl. Opt. *15*, 340 (1976).
26. R. A. McClatchey, W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfee, K. Fox, L. S. Rothman, and J. S. Garing, "AFCRL Atmospheric Absorption Lines Parameters Compilation," AFCRL-Report #TR-73-0096, Jan. 1973, unpublished.
27. S. G. Wechter, "Preparation of Stable Pollution Gas Standards Using Treated Aluminum Cylinders," paper presented at the ASTM Calibration Symposium, Boulder, Colorado, Aug. 1975.
28. See equation (1) of reference 18.
29. J. E. Lowder, K. G. P. Sulzmann and S. S. Penner, J. Quant. Spectrosc. Radiat. Transfer *11*, 1877 (1971).



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